LABORATORY MANUAL

FOR THE USE OF STUDENTS IN

TESTING MATERIALS OF CONSTRUCTION

BY

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PREFACE.

In 1908 the writer published a manual for the use of students in cement laboratory practice. The present volume contains nearly all of the matter included in the former work, in addition to which there are problems in the testing of other materials used in engineering construction, including tests of concrete, stone, brick, asphalt, sand and gravel, wood, iron, and steel. This volume is particularly intended for the use of those schools which include in one course all of the work in testing materials which is required of their students. However, a sufficient number of problems are outlined to permit the manual to be used in those schools in which the work is subdivided into two courses. If the entire field is covered by one course, it is probable that a considerable number of the problems will have to be omitted.

The Cement Laboratory Manual was prepared for the use of students taking the course in cement laboratory practice in the University of Illinois, and for the use of others requiring such a manual. Instructions for the problems originally used in the course mentioned were devised by Ira O. Baker, Professor of Civil Engineering, University of

Illinois, under whose direction the author had charge of the cement laboratory at that institution for three years. The Cement Laboratory Manual was prepared by revising and extending the instructions previously in use.

For suggestions and assistance in the preparation of the Cement Laboratory Manual, the writer is very much indebted to Professor Ira O. Baker.

L. A. W.

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MATERIALS TESTING MANUAL.

CHAPTER I.

GENERAL INSTRUCTIONS.

ART. 1. LABORATORY WORK.

1. **Methods.** There are two classes into which methods of testing may be divided, viz., direct and indirect methods. The first class includes all of those tests in which the character of the property under consideration is directly determined, either in the material or in a sample of it. The second class includes all of those methods by which the quality of the material is inferred from the results of tests upon related properties. For instance, it might be possible to determine the strength of a given material by breaking a sample, measuring the amount of the load used, or if it were known from the results of previous tests, or experience, that the specific gravity for satisfactory specimens had always been within certain limits, and that for unsatisfactory specimens the specific gravity had always been outside of those limits, then it might be possible to infer the quality of the material on hand by a determination of the specific gravity.

In many instances in which the quality of a material is inferred from the results of indirect tests, it requires but a slight variation in the results of the tests to reverse the indication as to the quality of the material. Since variations in the manner of conducting a test may cause a variation in the results, it is apparent that for certain kinds of tests all observers should follow uniform methods. Furthermore, there are cases in which variations in the method of preparing specimens, or in the method of treating a material, may cause considerable variation in the results of direct tests. For these reasons various organizations have attempted to standardize the methods of testing to be used for materials of construction. The American Society for Testing Materials has for its object this purpose, and its work in this direction is to be commended. The American Society of Civil Engineers and other organizations have also done a great deal of good work along the same line.

2. The student should make use of the standard methods of testing in order that he may gain a knowledge of those methods, that his results may be compared with the results obtained by other experimenters, and that his results may be of the greatest possible practical use in his own engineering practice.

3. **Care of Small Apparatus.** Small pieces of apparatus which are kept in lockers should be cleaned and returned to their places as soon as

possible after using. Use care in handling glassware. To remove cement which has set upon glassware vinegar or muriatic acid can be used. However, if glassware is thoroughly cleaned with water before the cement hardens, there will be no necessity for the use of acid.

4. **Use of Testing Machines.** No machine should be started without the approval of the instructor. Before starting a machine all tools, small pieces of apparatus, and other loose articles should be removed from the vicinity, or be so placed that they will not fall into the gears. Also, see that the machine is out of gear, with the driving belt running on loose pulleys.

5. In starting the electric motor, if such is used, allow the lever of the starting compensator to remain with the indicator at "Starting" until the motor has attained full speed, after which the lever should be shifted so that indicator points to "Running." Some small motors are used without starting compensators, in which case the full current is at once turned on by throwing the switch. If a motor of this kind is required to start with some belting and shafting connected, the strain in starting can be reduced by taking hold of the belt and giving it a start before throwing the switch. Before stopping the motor see that all machines which are driven by it are out of gear.

6. In preparing to use a large testing machine attach the necessary grips or the compression heads

which are required for the test to be made. Next see that the scale beam will balance for a zero load. If it does not balance shift the counterpoise as may be required. Then place the specimen in position in the machine, advance the poise on the scale beam far enough to cause the beam to drop, and move the lever to place the machine in gear. As soon as the scale beam rises, begin to move the poise forward, keeping the beam balanced until failure of the specimen occurs. Be careful not to move the poise beyond the point at which the failure occurs before taking the reading. As soon as the failure occurs, throw the machine out of gear and then record the reading of the load.

7. In using a testing machine the proper speed to use will depend upon the nature of the test. For compression tests of short specimens the slowest speed will usually be required. For ordinary tensile tests the next speed faster than the slowest will probably be satisfactory. The fastest speed should be used only for shifting the position of the movable head to facilitate placing or removing specimens.

8. In making tensile tests the specimen is held by two sets of grips, one set being attached to the fixed head and one set to the movable head of the machine. If the thickness or diameter of the specimen is small it is necessary to insert a filler plate between each grip and the machine head. The thickness of the filler plates or the number

used should be sufficient to prevent the grips from projecting from the head. In Fig. 1 the wrong

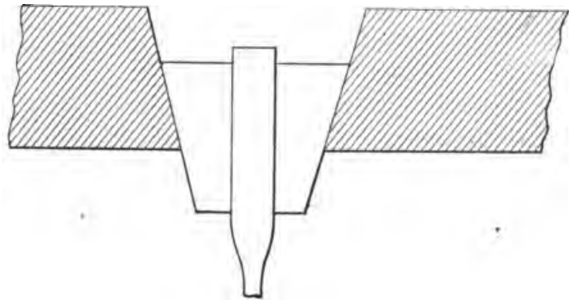

Fig. 1. — Wrong Way

way is illustrated, the filler plates being omitted, thus allowing the grips to slide down so far that they do not obtain full bearing against the head. The correct method is shown in Fig. 2.

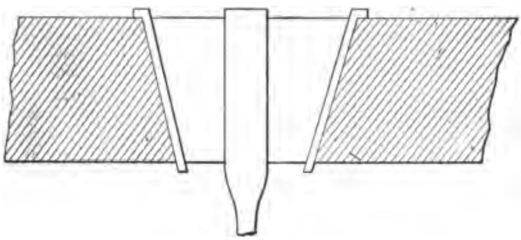

Fig. 2. — Right Way

9. Assignment of Equipment. For cement testing each student will be assigned a trowel, a pan, a beaker, and a graduated cylinder. He will also be assigned a locker in which to keep his

equipment. The number of the locker will be the same as the reference number of the student, by which assignments will be made. Other small pieces of apparatus which will be required will be kept in lockers provided for that purpose. The keys for these lockers will be kept in a key case, and can be obtained from the instructor. When a key is taken from its hook in the case, a receipt card is to be filled out by the student and placed upon the hook. Upon the card should be placed the date, the number of the key or locker, and the name of the person taking the key. This card is not to be removed when the key is returned, but it is to remain on the hook as a record. After returning the equipment to the locker, the key is to be deposited in the key case. In the event that any of the equipment is damaged, a record of the damage is to be made on a red tag, which is to be deposited with the key. Upon such red tags record the date, the article damaged, the locker in which the apparatus belongs, and the name of the person responsible for the damage. If apparatus is found to be damaged when a locker is assigned, the facts should be immediately reported to the instructor in charge.

10. Molds for making briquettes, sets of dies for marking specimens, rammers, oil cans, waste, and other equipment and supplies of this character, will be kept in suitable places provided for them. Whenever such equipment is used, it should be

returned to its proper place as soon as possible, in order that the work of other students may not be unnecessarily delayed.

11. **Assignment of Materials.** Each student will be assigned the materials to be used at each laboratory period. The assignments of cements will be made from two particular brands, one of which will be a Portland cement, and the other either a natural or a pozzuolana cement. For convenience each brand of cement will be given a number by which it will be designated upon the assignment sheet, but in reporting the results of problems the *name as well as the number* of the cement should be reported in every case. The assignment sheet will indicate whether one or both of the cements are to be used at one laboratory period. If desirable the same problem may be assigned for two different laboratory periods, only one cement being used at each period. Different kinds of sand will also be designated by number. Numbers from 1 to 49 inclusive will be reserved for Portland cements, numbers from 50 to 79 inclusive for natural cements, numbers from 80 to 89 inclusive for pozzuolana cements, and numbers from 90 to 99 inclusive for different kinds of sand.

12. **Waste Materials.** After using cement do not attempt to return it to the original bins or cans, even though it has not been mixed, but place it in the waste can provided for that purpose. If the cement is allowed to be returned to the original

supply, mistakes are likely to occur, and the various brands will soon become mixed. Do not place any unused mortar or other waste materials in the cans provided for unused cement. Waste boxes will be provided in which unused mortar, broken briquettes, and other wastes which are not liquid can be deposited. Very wet or liquid wastes are to be placed in the waste jar provided for them, and *under no conditions are wastes or water containing cement to be placed in the sink.*

13. **Assignment of Problems.** In order that an excessive amount of equipment may not be required, the problems will be assigned in such a manner that only a few students will be working on each problem at any one laboratory period. When more than one problem is to be executed at one laboratory period, the problems will be given on the assignment sheet in the order in which they are to be executed. It is important that the student shall observe the order in which the problems are to be done, particularly for assignments including the determination of the time of set, in which case the specimens should be prepared as quickly as possible at the beginning of the period, and while waiting for the setting to occur another problem can be executed. The letter *m* is used upon the assignment sheet to indicate the laboratory periods at which specimens are to be made, and the letter *t* to indicate the periods at which specimens are to be tested.

14. **Marking Test Specimens.** In some of the problems instructions are given for marking specimens which are to be tested at some future laboratory period. The student should be careful to follow these instructions, since it is desirable to have all the members of the class use a uniform method, in order that the attendant who cares for the specimens may know where they belong.

ART. 2. PREPARATION OF REPORTS.

15. A report is to be made out for each problem and is to be handed in within three days after the completion of the problem in the laboratory. Each problem is to be reported upon a separate sheet, even though the laboratory work for several problems may be executed at one laboratory period. It is also desirable to have the report for each problem occupy but one page. In order that reports may be uniform, it is essential that each student shall use only the kind of paper designated for such reports, and the use of other kinds of paper will be sufficient cause for the rejection of reports.

16. In addition to the reports to be submitted for the separate problems, the student will be required to submit a final report upon each of the two cements used. Each of these final reports shall contain a summary of the results of the tests which have been made upon the brand of cement under consideration, and in conclusion a statement shall be made concerning the character of the

cement as indicated by the results of the various tests. In this statement name the kinds of work for which the cement would be satisfactory and the kinds of work for which it might prove unsatisfactory. Also compare the results with the specifications recommended by the American Society for Testing Materials, which are given in Appendix II.

17. It is essential that both the reports of the problems and the final reports shall be carefully prepared. Forms for these reports are not given, for the reason that it is desired that students shall take the initiative and that they shall learn to devise reports. For much of the school work, forms of notes are furnished which show the exact way in which to record the various data and results obtained. Cement laboratory work may be different from the other work which the student has done, and many of the engineering problems for which he will have occasion to devise reports will undoubtedly be different from any of his previous work; but, if he will study the methods used in the arrangement of a few kinds of work, he should be able to apply those methods to other kinds of work. For this reason the student is asked to study carefully the arrangement of his reports. In devising forms for reports, the following things should be remembered: A report should be terse, precise, complete, and neat. In order that it may be neat, it must be not only well arranged, but also

legibly written or lettered. In order that a report may be complete and at the same time terse, all of the necessary facts should be stated, but each fact should be stated as briefly as may be without detracting from the precision of the statement. It is well to tabulate all data and all results which can be expressed in such form. Similar kinds of facts should be collected and arranged under suitable headings, as "Object of Experiment," "Apparatus," "Method of Determination," "Data and Results," "Conclusions," etc. Such headings should be given sufficient prominence to enable anyone to see at once where the facts for which he is looking may be found. It is not advisable to use symbols in headings for tabulated data, as % for per cent. Also avoid the use of abbreviations in the title and other headings of the report.

CHAPTER II.

DESCRIPTION OF APPARATUS.

18. In order that the student may better understand the problems in the following chapters, some of the apparatus commonly found in testing laboratories will be briefly described.

19. Cement Sampler. The device shown in Fig. 3 is used for obtaining samples for inspection from cement packed in barrels.

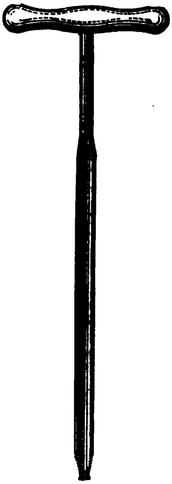

Fig. 3. — Cement Sampler

Fig. 4. — Single Sieve

Fig. 5. — Nest of Sieves with Cover and Pan

20. Sieves. Coarse sieves are used for screening cement to remove lumps, and fine sieves are used

for determining the fineness of cement. Both classes of sieves are designated by number, the number of meshes per lineal inch being the same as the number of the sieve. The styles of sieves ordinarily used in cement laboratories are shown in Figs. 4 and 5. Fig. 4 illustrates a single sieve, and Fig. 5 a nest of sieves arranged to fit together, with a cover on the top sieve and a pan attached to the lower sieve.

21. Apparatus for Determining Weight of Cement. For the purpose of determining the

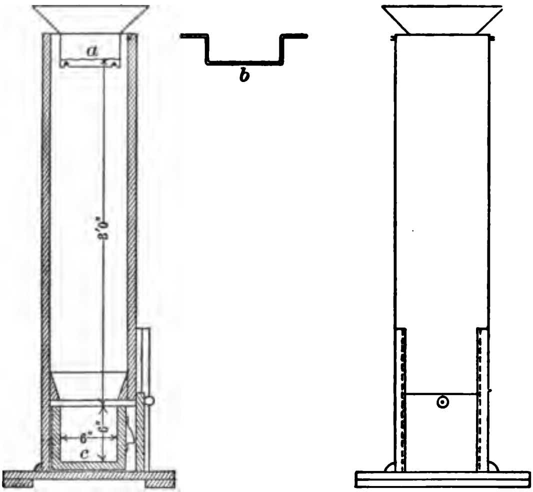

Fig. 6. — Apparatus for Determining Weight of Cement

weight of cement per cubic foot or per bushel, the measuring box used must be so arranged that the

amount of compacting which the cement receives in entering the box shall be the same for the different samples tested, since the weight varies considerably with the degree of compactness. The device shown in Fig. 6 produces a uniform compactness by allowing the cement to fall from a coarse sieve *a*, suspended on hangers *b* to permit shaking, and fixed at a distance of three feet above the top of the measuring box *c*.

Fig. 7. — Sandglass

22. **Sandglass.** For the purpose of indicating the time of mixing to be used for making cement paste, a sandglass, Fig. 7, is employed. Such glasses can be purchased, having a duration of flow of about two minutes.

23. **Trowels.** For use in cement laboratories pointing trowels, Fig. 8, or masons' trowels, are most useful. The most convenient sizes are five-inch, six-inch, and ten-inch trowels.

Fig. 8. — Mason's Trowel

24. **Balances and Scales.** For most of the weighing to be done in a cement laboratory the Harvard trip balance, Fig. 9*a*, or a scale with a

scoop, Fig. 9*b*, will be found satisfactory. The latter balance is probably a little better, since no time is required to balance the pan.

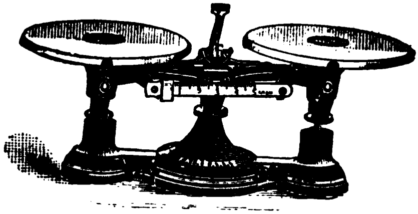

Fig. 9*a*. — Harvard Trip Balance

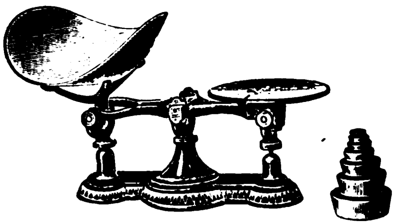

Fig. 9*b*. — Scale for Cement and Sand

Fig. 10. — Triple-Beam Balance

25. For use in making specific gravity determinations a balance of better quality should be used, but it is not necessary to use a fine balance of high grade. The triple-beam balance, shown in Fig. 10, is entirely satisfactory.

26. For determining the fineness of cement a special scale, Fig. 11, is much used. This scale has a set of weights which have a unit such that 1000

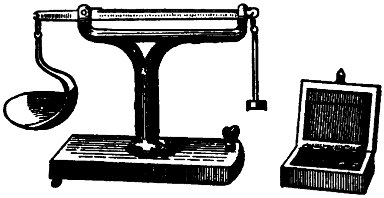

Fig. 11. — Scale for Determining Fineness of Cement

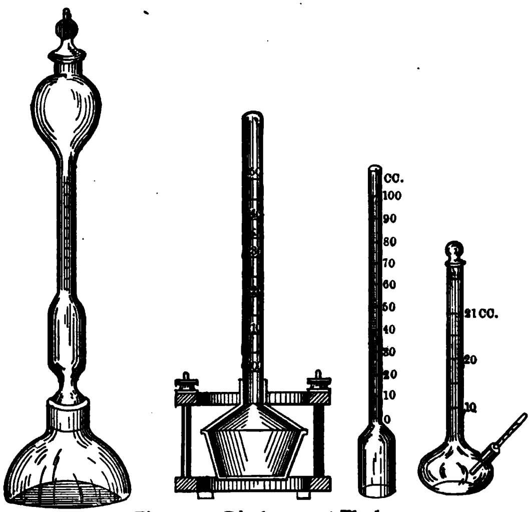

Fig. 12. — Displacement Flasks

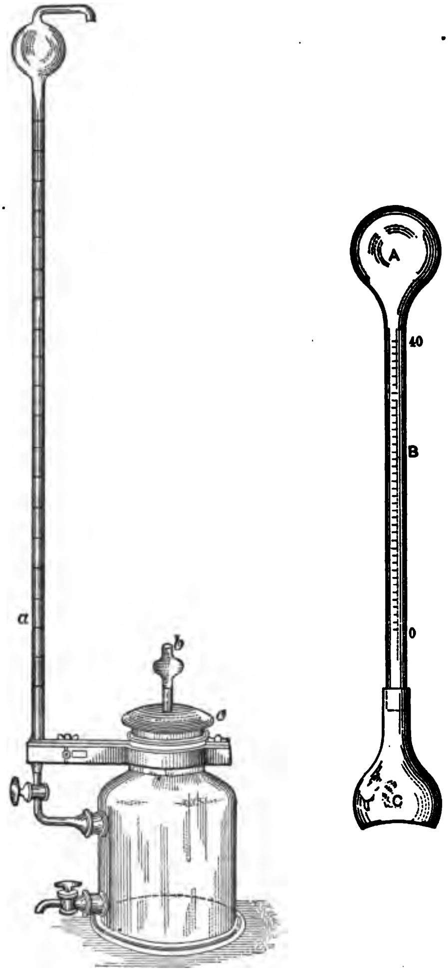

Fig. 12a. — Displacement Flasks — ***Continued***

units of cement will be a convenient quantity for one determination, and thus each unit is equivalent to one-tenth of one per cent of the total.

27. **Displacement Flasks.** For the purpose of determining the specific gravity of cement, a flask is used which is graduated to indicate the volume displaced by the introduction of a small quantity of cement into the liquid within the flask. Various types of flasks can be obtained from the makers, some of which are shown in Fig. 12. The apparatus recommended by the American Society of Civil Engineers is the Le Chatelier's flask, which when in use is to be immersed in a jar of water to reduce the amount of the variation in the temperature of the liquid within the flask. The Le Chatelier's apparatus is illustrated and described in Appendix I, page 179.

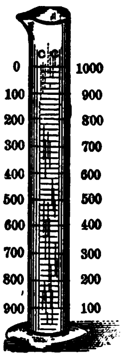

Fig. 13.—Graduated Cylinder

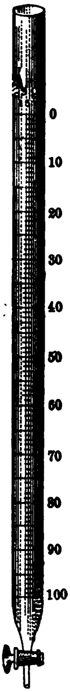

Fig. 14.—Burette

28. **Measuring Glasses.** For the purpose of measuring the quantity of water to be used in making cement paste or mortar, a graduated cylinder, Fig. 13, will be found useful. The sizes which will usually be of the most service are those having capacities of 100 c.c., 250 c.c., and 500 c.c. It is desirable to have both a small-sized and a large-sized cylinder at hand.

29. If water is piped to the mixing table a burette, Fig. 14, may be fastened beneath the tap and water measured in the burette.

30. Vicat Apparatus.* The Vicat apparatus, Fig. 15, is a device for measuring the distance which

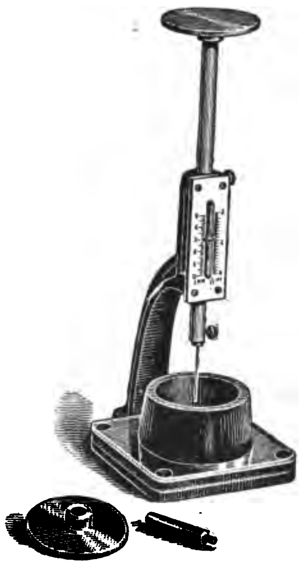

Fig. 15. — Vicat Apparatus

a weighted needle or weighted plunger will penetrate a ring filled with cement paste. There are two caps for each machine. The lighter cap is to be used only when the plunger is attached to the lower end of the piston, and the heavy cap is to be used

* For a further description of the Vicat apparatus, see Appendix I, page 183.

only when the needle is in use. Care must be exercised to see that the proper cap is being used.

31. The Vicat apparatus is used for determining the proper percentage of water to be used in gauging the cement, and also for determining the rate of setting. The plunger is employed for the first purpose and the needle for the latter.

32. **Gillmore's Needles.** Another instrument for determining the time of setting of a sample of cement paste is Gillmore's needle, which consists of weighted wire or needle which is held in the hand and is brought to rest upon the surface of the paste. Two needles, Fig. 16, are required, one having a

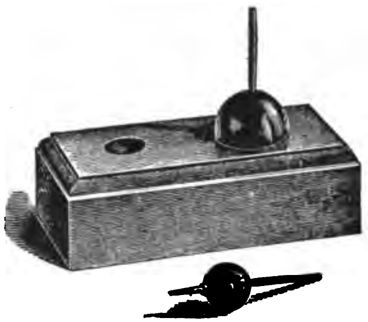

Fig. 16. — Gillmore's Needles

weight of one-fourth pound and a bearing area of one-twelfth inch, and one having a weight of one pound and a bearing area of one-twenty-fourth inch. The initial set is said to have taken place when a pat of cement will just support the light wire, and the final set when it will support the heavy wire.

33. **Molds.** The molds ordinarily employed in making specimens for determining the tensile strength of cement mortar are of two kinds, individual molds and gang molds, both of which are illustrated in Fig. 17. The form of briquette which is

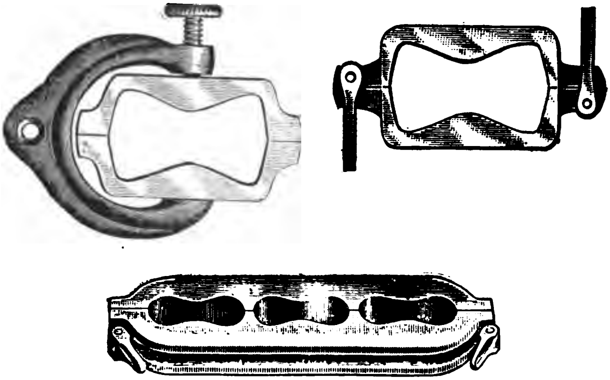

Fig. 17. — Briquette Molds

recommended by the American Society of Civil Engineers is shown in Fig. 63, page 188.

34. For the purpose of making specimens for compression tests of cement mortar, one-inch and two-inch cube molds, similar to the one shown in Fig. 18, are ordinarily used.

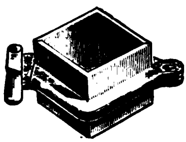

Fig. 18. — Cube Mold

35. Molds for concrete specimens are usually made of wood.* Cast-iron molds for six-inch cubes similar to Fig. 18 are sold by the manufacturers,

* For molds for shear specimens see page 95.

and for cylindrical specimens molds similar to that shown in Fig. 19 are obtainable. Wooden molds for laboratory use should be made of material which is sufficiently heavy to prevent it from

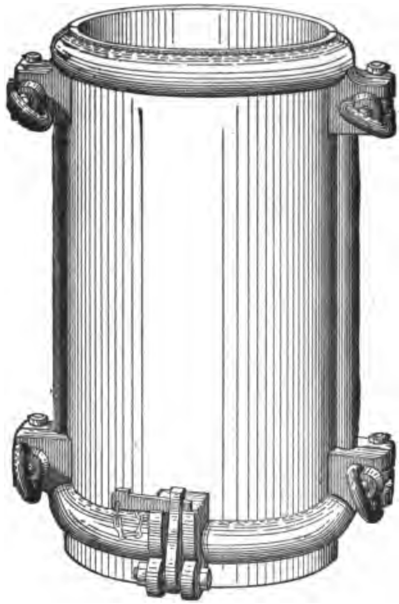

Fig. 19. — Cylindrical Mold

springing out of shape while casting the concrete, should be carefully made to insure true specimens, and should be held by clamps in such a manner that the molds can be easily removed from the specimens, and easily put together for casting new specimens. One convenient arrangement is shown

in Fig. 20, in which the pieces *a* are the sides of the mold, *b* is the piece forming the end of the mold, and is held in place by resting in a groove in each side piece. The pieces *c* of the clamp are held in place by a spreader *d* at the top and a bolt *e*. To remove the clamp the bolt *e* is loosened just enough

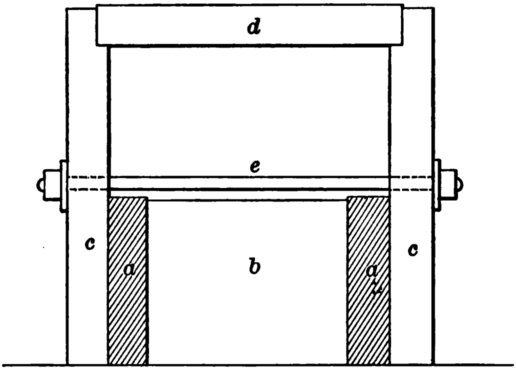

Fig. 20. — Cross Section of Mold for Concrete Beams

to permit the spreader *d* to be removed, after which the clamp may be withdrawn from the mold, and the sides of mold can then be removed.

36. **Molding Machines.** The most common method of molding briquettes is by hand, although machines for this purpose can be obtained from the manufacturer. Two machines of this kind are the Olsen press, Fig. 21, and the Böhmé hammer, Fig. 22. With the Olsen press the briquette is molded by rotating the hand wheel which presses the mortar into a mold held in a clamp at the top

Fig. 21. — Olsen Press

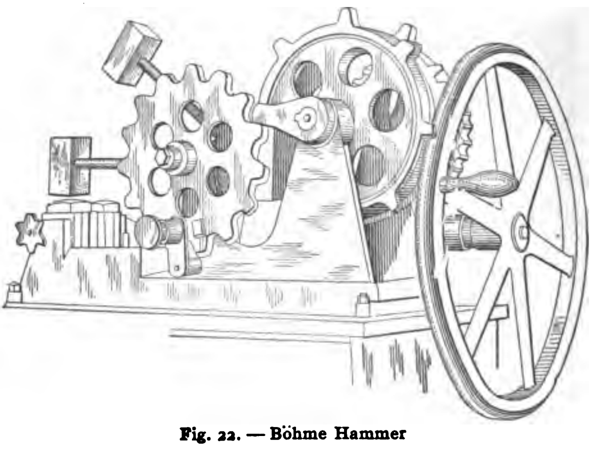

Fig. 22. — Böhme Hammer

of the machine. The amount of the pressure is recorded by the dial attached to the machine. With the Böhmé hammer the briquette is molded by compacting the mortar with a fixed number of blows of a hammer, the machine being arranged to stop automatically when the proper number of blows have been given.

37. The greatest value of briquette molding machines in a laboratory is to illustrate the effect of different methods working cement mortar. The two machines illustrated in Figs. 21 and 22 are examples of the two classes into which all molding machines might be divided, viz.: (1) Machines in which a steady pressure is employed, and (2) Machines in which the mortar is compacted by a blow. A comparison of the results obtained from two such machines is of value to a student to indicate the probable effect of different methods of manipulating cement in practical work.

38. **Boiler for Accelerated Tests.** For use in making boiling and steam tests a closed vessel is employed, having one or more racks upon which the specimens are placed. If the vessel is used for both boiling and steam tests, it is necessary to have two racks, one of which shall remain above the water level, and one below. The boiler recommended by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers is shown in Fig. 66, page 193. This boiler is intended for steaming tests only, and therefore is

provided with but one rack. This apparatus is arranged to maintain the level of the water three inches above the top of the boiler.

39. **Moist Closet.*** A moist closet is a box or chamber arranged so that the air within may be kept moist. It is used for the storage of test specimens from the time of making until they are immersed in water, usually twenty-four hours.

40. In some laboratories the test specimens are placed under a wet cloth instead of being placed in a moist chamber. The principal objection to this is that the cloth is likely to dry out, and is then of no service. To maintain the cloth in a moist condition the ends may be immersed in water, or a large pan may be turned upside down over the specimens and cloth. Of these two methods the writer prefers the latter, because he believes that it will produce a more nearly uniform condition for all of the specimens than will the first method. If a pan is used it should entirely cover all of the objects beneath it so that the entire rim of the pan may rest upon the table, thus preventing air currents from carrying away the moisture. If these precautions are observed, there will be no difficulty in maintaining a moist condition of the cloth and air for twenty-four hours.

41. **Storage Tank.** Test specimens are usually stored in water from the time they are removed

* See paragraph 63, page 190.

from the moist chamber until they are tested. For this purpose a storage tank is required which shall have a sufficient capacity to accommodate all of the specimens which are likely to be in storage at one time. For convenience in using, such a tank should have a waste pipe, an overflow pipe leading to the waste pipe, and a supply pipe. If the tank is in a place which is open to the public, it is well to have the valves controlling the supply and waste pipes either locked or in a position such that they are not likely to be disturbed. It is also advisable to have a cover upon the tank which can be locked, so that specimens which are kept in storage for long-time tests may not be disturbed.

42. **Cement Testing Machines.** For the purpose of determining the tensile or the compressive strength of test specimens a testing machine is used. A great variety of machines are upon the market, of which three styles of machines for determining the tensile strength of cement are shown in Figs. 23, 24, and 25, and one type of machine for determining the compressive strength of small specimens is shown in Fig. 26. Some machines are arranged so that they may be used for both tensile and compressive tests. However, since very few compressive tests of cement are made, most of the testing machines employed are for tensile tests. For testing concrete, compressive tests are often made, but for this purpose large testing machines are employed.

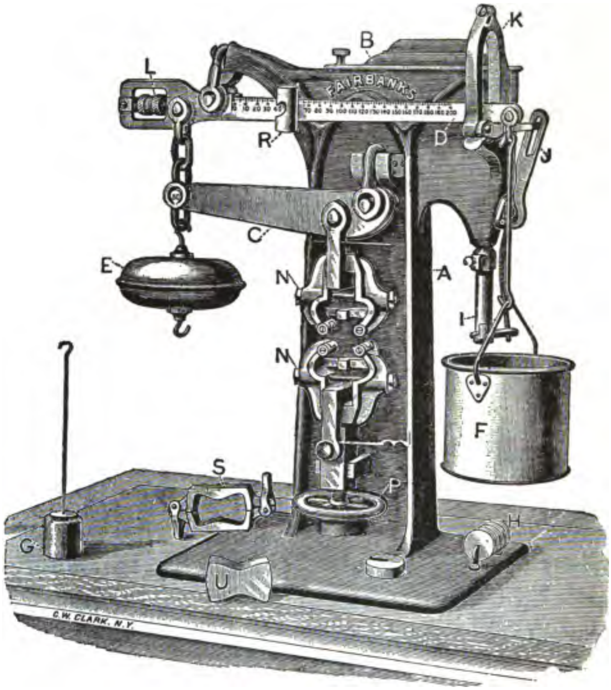

Fig. 23. — Automatic Testing Machine

43. The most common types of cement testing machines produce a stress upon the briquette by means of a stream of shot which runs from a chamber of the machine into a pail or vessel. When the briquette breaks, the stream of shot is automatically stopped, and the amount of the stress is determined by weighing or noting the weight of the shot in the vessel. The scale employed in the

weighing is so graduated that it indicates directly the stress upon the briquette, instead of the actual weight of the shot. The more improved forms of machines are arranged so that the beam of the

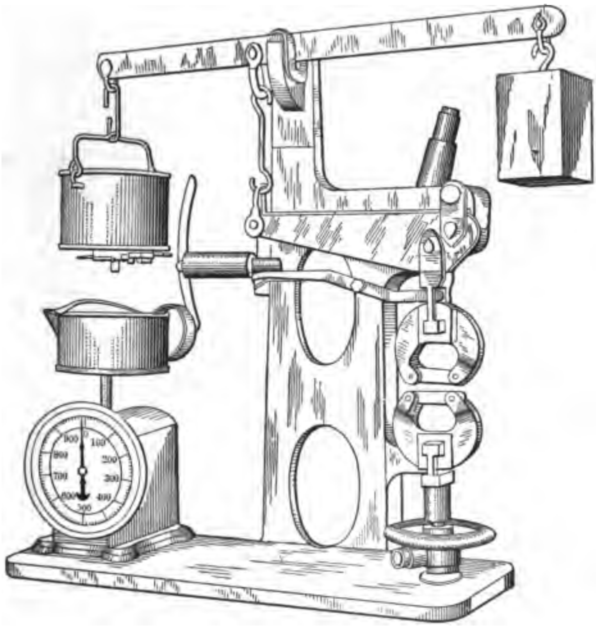

Fig. 24. — Automatic Testing Machine

machine can be kept horizontal while the stress is being applied. If this cannot be done, it is usually necessary to estimate the amount of tension which must be applied to the briquette in placing it in the machine, in order that the beam may be nearly

horizontal when the specimen breaks. The result is that weak specimens are often broken while being placed in the machine, and very strong specimens have to be reset in the machine, during which process they are likely to be broken.

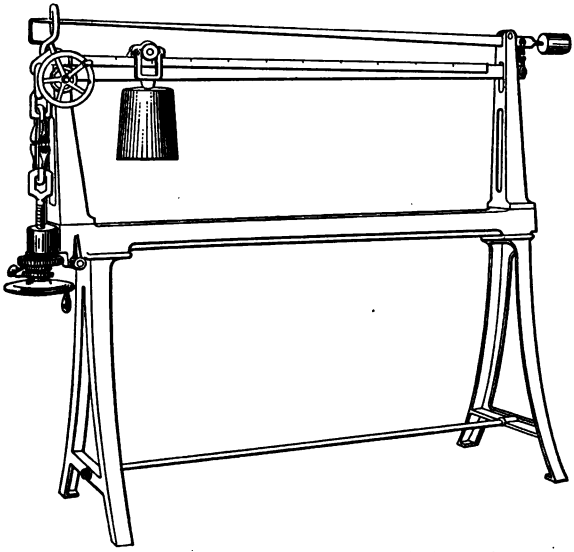

Fig. 25. — Cement Testing Machine with Moving Weight

44. The capacities which are usually employed for tensile-testing machines are 1000 and 2000 pounds. For ordinary laboratory work the lower capacity is probably the better, since very few briquettes will exceed 1000 pounds in strength, and since the lighter machine will act a little more quickly in shutting off the supply of shot.

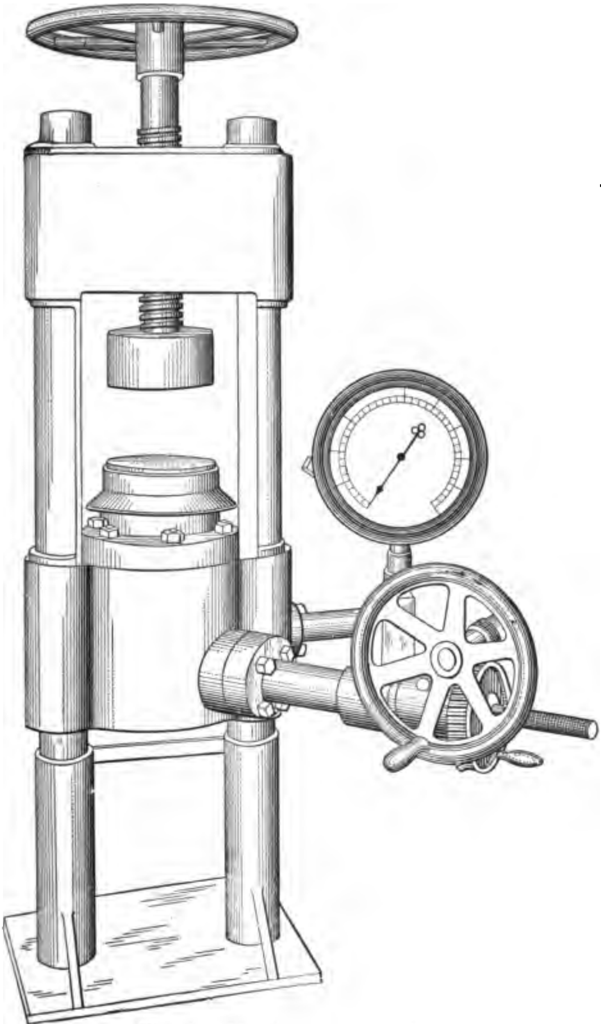

Fig. 26. — Machine for Compressive Tests

45. Hydraulic Testing Machines. A considerable number of hydraulic testing machines of various types and sizes are in use, two of which are illustrated in Fig. 26 and Fig. 27. The first is

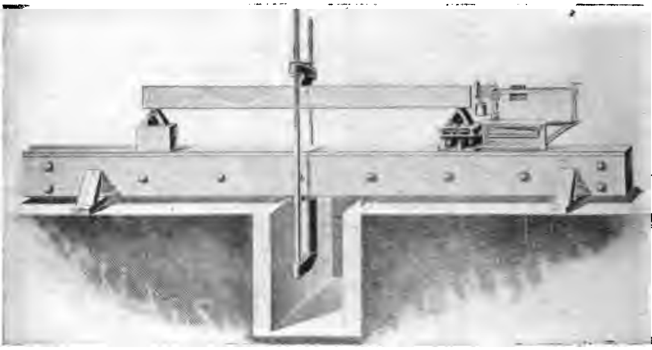

Fig. 27. — Hydraulic Transverse Testing Machine

for compression tests and has a capacity of 40,000 pounds. It is particularly adapted to making compression tests of small specimens of concrete. The second is for transverse tests and has a capacity of 100,000 pounds. A common method of measuring the load which is applied with hydraulic machines is by means of a pressure gauge which is affected by the pressure of the liquid in the cylinder containing the plunger. This arrangement is illustrated in Fig. 26. The objections to this method of determining the load are that the friction of the plunger may slightly affect the results and that the calibration of the pressure gauge may need to be checked occasionally. The machine

shown in Fig. 27 avoids these objections by employing a scale beam which is independent of the hydraulic cylinder.

46. Vertical-screw Testing Machines. The most common type of testing machine which is

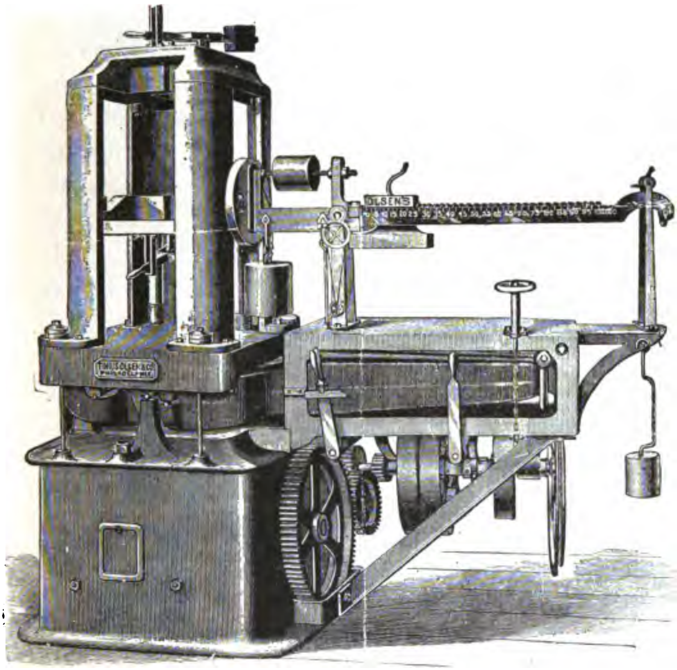

Fig. 28. — Vertical-screw Testing Machine

employed in laboratories for tensile, compressive, and flexural tests of wood, iron, and steel is the vertical-screw testing machine. A large number of styles of these machines are manufactured,

some of which are particularly suited for certain kinds of tests. One of the common types is shown in Fig. 28. Similar machines can be obtained with maximum capacities ranging from 10,000 to 400,000 pounds. Machines with even larger capacities can be built, which utilize the same method of applying and measuring the load. Machines which are intended for testing columns have long vertical screws and long upright standards, and those which are intended for testing long beams have wings attached to opposite sides of the platform.

47. Vertical-screw testing machines are made with two screws and with three screws as well as with four screws. A two-screw machine which is adapted to a large range of tests is shown in Fig. 29. This machine has an upper head which can be shifted to accommodate specimens of various lengths, the standards being long enough to accommodate tensile and compressive specimens six feet in length. It is also provided with a long table for transverse specimens. The capacity of this machine is 300,000 pounds.

48. The machine which is shown in Fig. 28 has one movable head which is attached to four vertical screws. The screws pass through loose holes in the platform of the machine to the gears in the base of the machine. The movement of these gears causes the vertical screws and the attached head to move up or down as desired. The load is

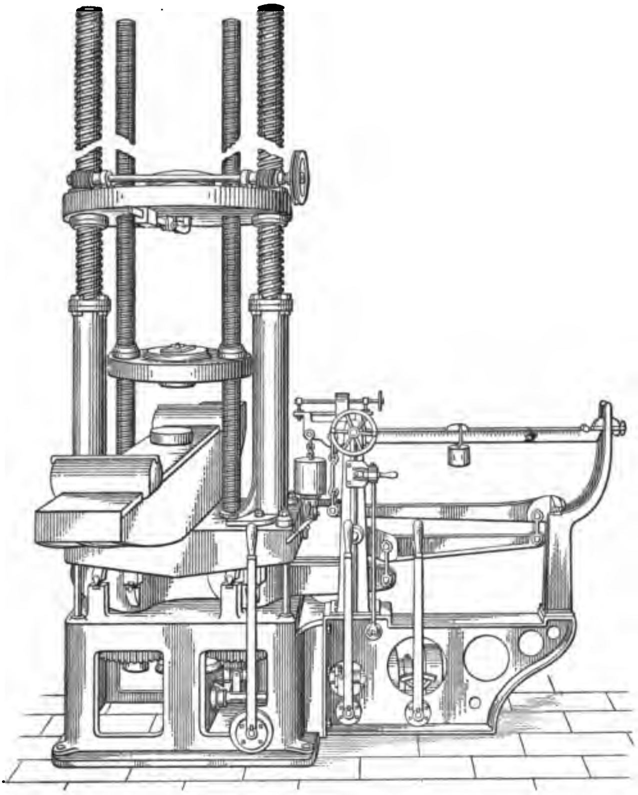

Fig. 29. — Two-screw Testing Machine

applied only with the downward movement. The platform of the machine is supported by levers, which are connected with the scale beam. Upon the platform are four vertical standards to which the upper head of the machine is rigidly attached.

In making tensile tests the specimen is held at the upper end by grips attached to the fixed head, and at the lower end by grips attached to the movable head. As the movable head moves downward the specimen is elongated, the amount of the pull being transferred to the platform through the vertical standards, the amount of which load is then measured by the scale beam. As the load increases the poise of the scale beam is moved forward to keep the beam balanced.

49. For compression tests the grips are removed from the lower head and a bearing plate is attached to the under side of the head. The specimen is placed between the bearing face and the platform. As the head moves downward the specimen is compressed and the amount of the load which is transferred to the platform is measured by the scale beam, as described for tensile tests.

50. **Transverse Testing Machines.** For the purpose of testing large beams of wood, steel, and reinforced concrete, vertical-screw testing machines are generally used. However, for class use in testing small wooden beams, particularly for specimens which are sufficiently slender to obtain good observations of the deflection, a machine of smaller capacity than most vertical-screw testing machines is desirable. For this purpose the machine illustrated in Fig. 30 is well adapted. It has a capacity of 10,000 pounds and will take specimens

three inches square, with a length not exceeding five feet. By using slender specimens the deflection at any point can be fairly well determined by direct

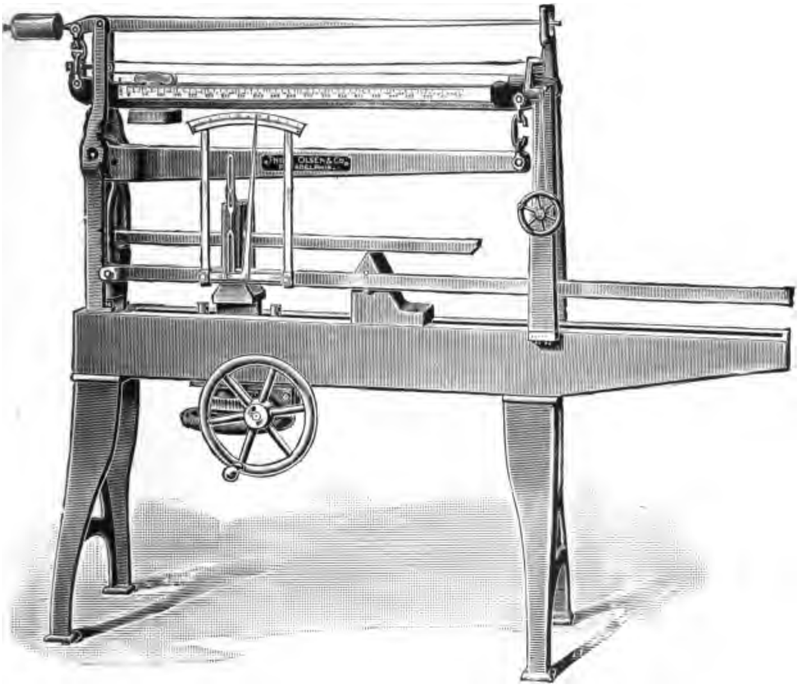

Fig. 30. — Transverse Testing Machine for Small Specimens

measurement with a rule or scale, or the deflection can be observed with the device shown in the cut.

51. Torsion Testing Machines. In Fig. 31 is shown one style of machine for making torsion

tests of steel shafting. The specimen is held at each end by chucks, one of which is rotated by gear wheels, while the other is connected to a scale beam, which indicates the amount of the load in

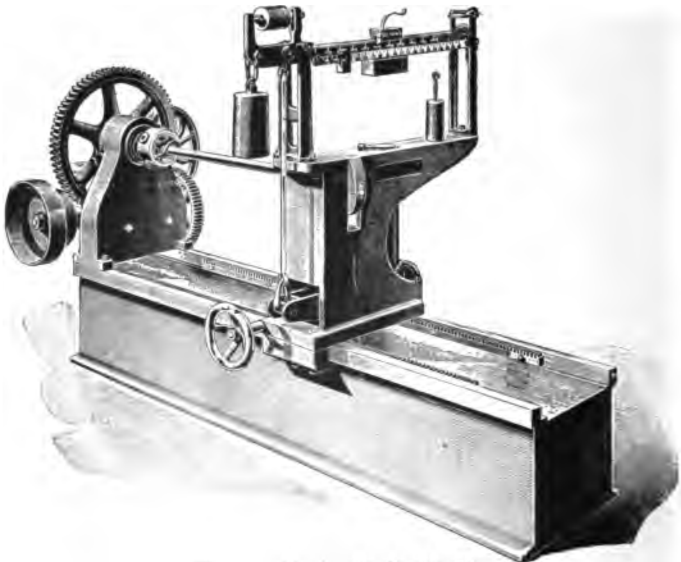

Fig. 31. — Torsion Testing Machine

pound-inches. The heads of the machines are graduated in degrees, for observing the amount of the twist.

52. **Impact Testing Machines.** Two types of machines for making impact tests are illustrated by Figs. 32 and 33. In each case the machine indicates the energy of the blow upon the specimen, the energy being determined by knowing the

weight of the hammer and the distance through which it falls. The first type of machine is adapted to comparatively small sizes, but the machine

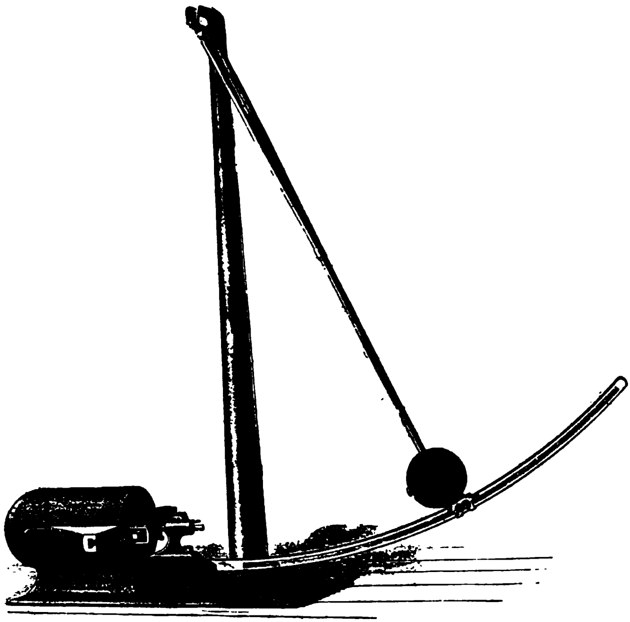

Fig. 32. — Heisler Impact Machine

shown in Fig. 33 can be obtained in sizes suitable for testing large specimens.

53. In Fig. 34 is shown an impact machine which is used for testing the toughness of macadam rock. The machine consists of an anvil of 50 kg. weight, to which is connected the frame carrying the operating parts. The hammer weighs 2 kg.

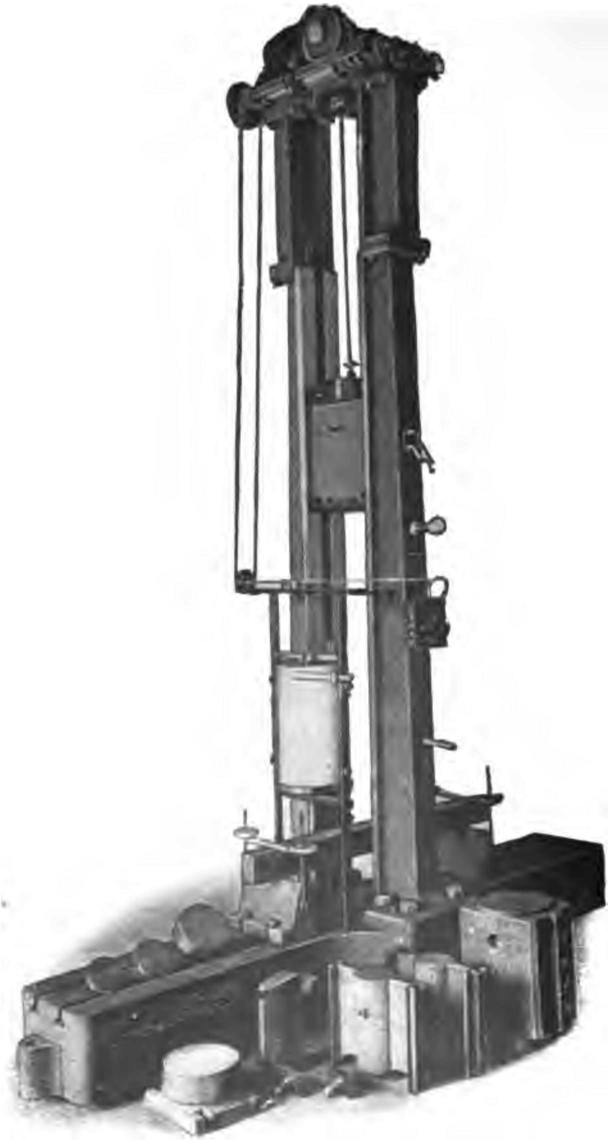

Fig. 33. — Turner Impact Machine

Fig. 34. — Impact Machine for Macadam Rock

and is arranged so it may be dropped by increments of 1 cm. up to 90 cm. upon an intervening plunger of 1 kg. weight, which rests on the test piece. The hammer is drawn up by power and is automatically released at the point set by the operator.

54. **Cold-bend Testing Machines.** A machine for making cold-bend tests of iron and steel specimens is illustrated in Fig. 35. The specimen can be bent through an angle of 180 degrees. The nature of the bend or the point at which fracture occurs is observed.

55. **Abrasion Cylinders.** Abrasion tests of paving brick are made with an abrasion cylinder or rattler. The standard rattler test recommended by the National Brick Makers' Association is made with a rattler of the type shown in Fig. 36, the cylinder frequently being enclosed in a dust-proof case. With this machine the brick to be tested are dumped into the cylinder with the specified charge of cast-iron shot, and after the prescribed number of revolutions the loss by weight, due to the abrasion, is determined.

56. An abrasion cylinder designed by Professor A. N. Talbot, of the University of Illinois, consists of a short cylinder, the inside circumference of which is covered with the brick to be tested. The brick are clamped in place, and as the cylinder revolves the abrasive materials impinge upon the exposed edges of the brick.

Fig. 35. — Cold-bend Testing Machine

Fig. 36. — Abrasion Cylinder for Brick Tests

57. The abrasion machine shown in Fig. 37 is used for abrasion tests of stone for road construction. The cylinders are each 20 cm. in diameter by 34 cm. in length and are mounted at an angle of 30 degrees with the axis of rotation. No abrasive material in addition to the stone is used with this machine.

Fig. 37. — Abrasion Cylinders for Macadam Stone

58. Micrometers. For the careful measurement of the diameter or size of cross section of small specimens either a micrometer, similar to that shown in Fig. 38, or a pair of slide calipers is suitable. For the measurement of flat specimens two micrometers are useful, in order that one may be allowed to remain at the approximate setting for the width, while the other is at the approximate setting for the thickness.

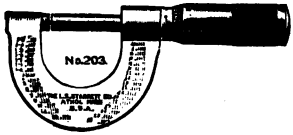

Fig. 38. — Micrometer

59. Laying-off and Per-cent Gauge. The laying-off gauge, shown in Fig. 39, is used in marking steel tensile specimens and in measuring the elongation. The gauge is first laid upon the specimen and a length of eight inches is divided into one-inch spaces by means of a scratch awl. After rupture the two pieces of the specimen are laid together, with the fractured ends joining, and the gauge is used to measure the elongation. The units of the graduation at the end of the gauge are one per cent of the gauge length (eight inches). By observing the marks which were originally one inch apart the elongation for each inch can be noted.

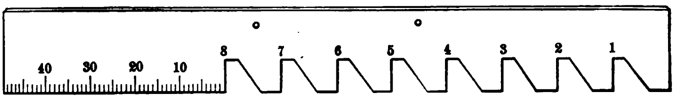

Fig. 39. — Laying-off and Per-cent Gauge

60. Extensometers and Deformeters. An extensometer is a device for measuring the elongation in a given length of a specimen which is sub-

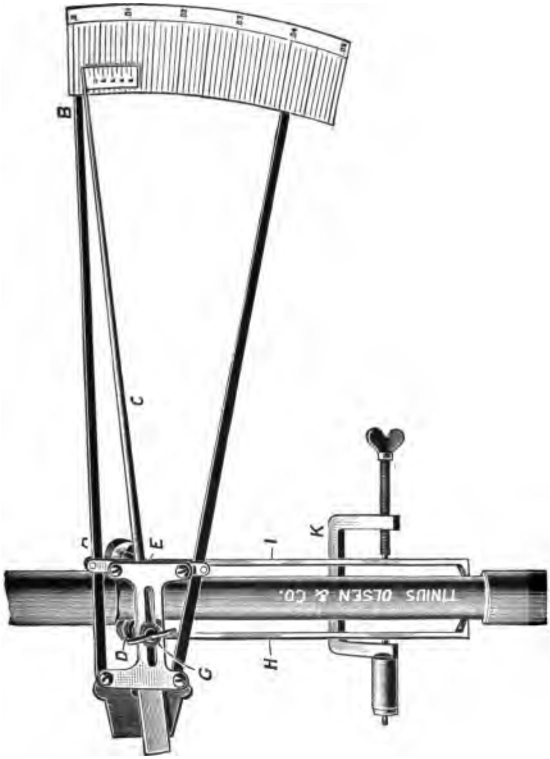

Fig. 40.—Deformeter for Tension and Compression Tests

jected to tension. A deformeter is a device for measuring the deformation which occurs in a given length of a specimen. The two most common principles employed in instruments of this kind

are the micrometer and the vernier and dial. Two applications of the vernier and dial are shown in Figs. 40 and 41, both instruments being adapted to the measurement of the deformation for tests

Fig. 41. — Deformeter for Tension and Compression Tests

either in tension or in compression. Three micrometer instruments are shown in Figs. 42, 43, and 44. The first is for tensile tests, the second for compressive tests, and the third may be used for

either, but it is intended for specimens of concrete in the form of cylinders eight inches in diameter. In using the micrometer instruments the parts are

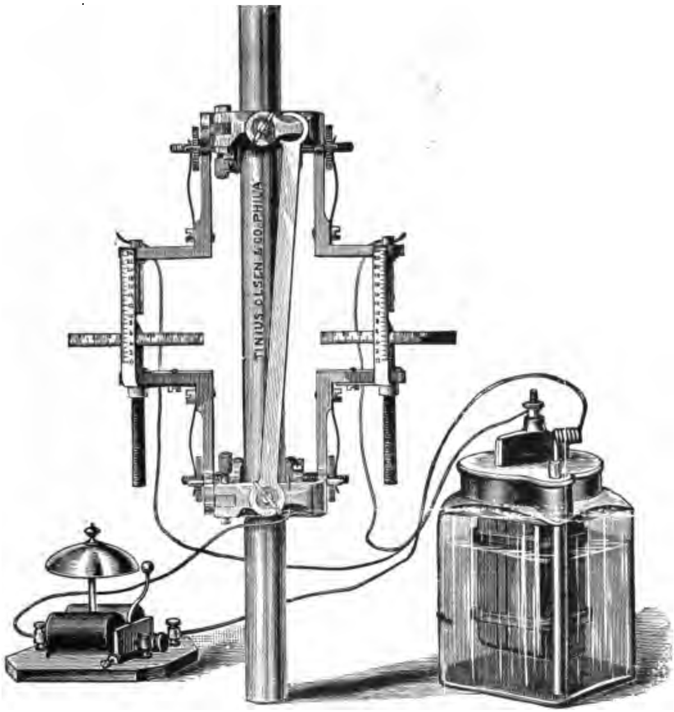

Fig. 42. — Duplex Micrometer Extensometer

connected to an electric bell circuit in such a manner that the circuit will be closed by bringing the point of either micrometer in contact with its bearing surface. As soon as the bell rings the reading

Fig. 43.—Duplex Compression Micrometer

of the micrometer is observed, and the micrometer screw is run backward far enough to prevent further contact until another reading is desired.

61. Two deformeters for use in testing beams and columns are shown in Figs. 45 and 46.

Fig. 44. — Duplex Deformeter for Concrete

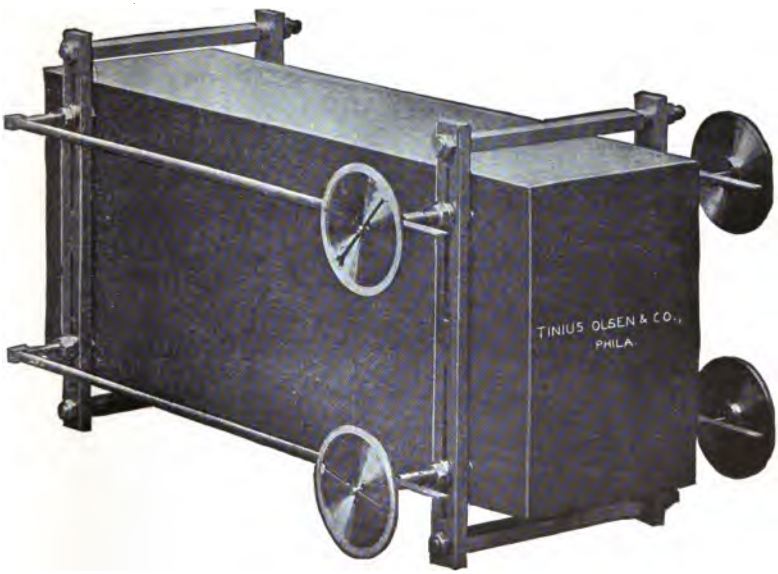

Fig. 45. — Dial Deformeter for Beams

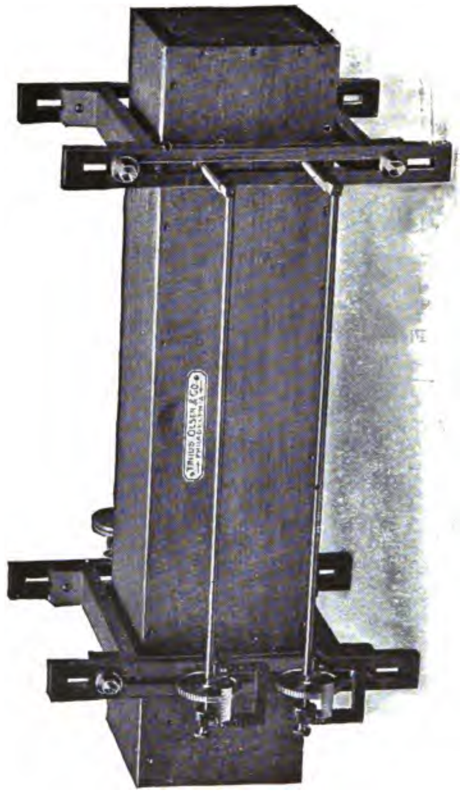

Fig. 46. — Micrometer Deformeter for Beams

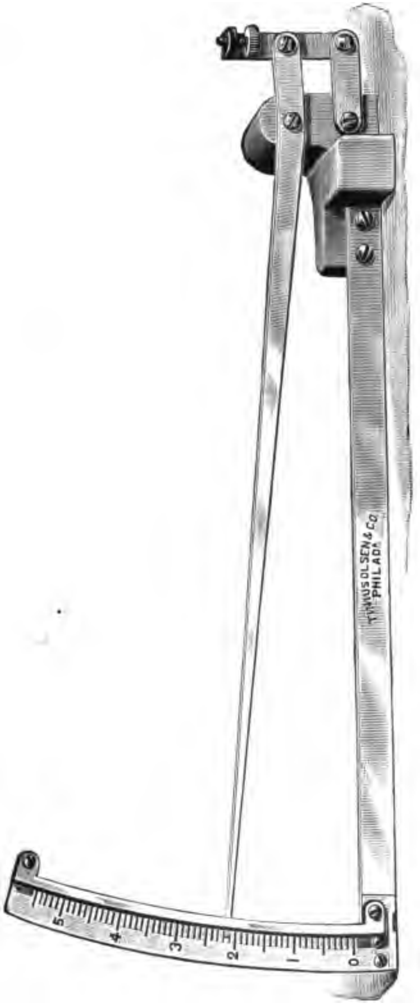

Fig. 47. — Deflection Indicator

62. Deflection Instruments. For measuring the deflection of small beams, such as specimens of cast iron, the deflection instrument shown in Fig. 47 is suitable. These instruments can also be obtained with a vernier attached to the end of the indicator arm. The scale reads directly to 0.01 inch of actual deflection and the vernier reads to 0.001 inch.

Fig. 48. — Capp's Multiplying Dividers

63. Multiplying Dividers. The instrument shown in Fig. 48 is used in determining the yield point of metal specimens tested in tension. Two prick marks are made on the test piece, two inches apart, and the dividers are held against the specimen with the points in the prick marks. The motion of the pointers is watched, and the yield point is determined by noting the load at which the rate of travel of the pointer suddenly increases.

CHAPTER III.

TESTS OF CEMENT.

PROBLEM A1.

Determination of Fineness of Cement.

64. **Object.** The object of this experiment is to determine how finely the given samples of cement have been ground.

65. **Apparatus Required.** One set of sieves * with cover and pan, scale for testing fineness, or a fine balance, with set of weights, apparatus for drying cement, and one No. 20 sieve.

66. **Materials Required.** 50 or 100 grams of each assigned cement.

67. **Method of Operation.** Thoroughly dry the cement, and then screen a small quantity through the No. 20 sieve, to remove the coarse lumps. Of the cement which passes through the sieve weigh out 1000 units if Riehle's scale for fineness is used, or 50 grams if a fine balance is used. Place the quantity thus weighed upon the No. 200 sieve, having the pan attached at the time. Place the cover upon the sieve and shake, holding the sieve

* The set of sieves should include a No. 100 sieve and a No. 200 sieve.

in a slightly inclined position, and strike it gently with the palm of the hand at the rate of about 200 strokes per minute. Continue this operation until not more than one-tenth of one per cent passes through during one minute of continuous sieving. Then weigh the residue retained upon the sieve and also the material in the pan. Next attach the No. 100 sieve to the pan, and place upon the sieve the residue caught upon the No. 200 sieve. The sieving is then continued in the same manner as with the No. 200 sieve. After completing the operation with this sieve the residue is placed upon the next coarser sieve, and so on until all of the sieves in the set have been used.

68. After completing the determination for one of the assigned cements determine the fineness of the other brand in the same manner.

69. Report. In the report state the quantities retained and the quantities passing each sieve. Also report the per cent of the total which is retained upon each sieve and the per cent which passes, stating the results to the nearest tenth of one per cent. Compare the results with the specification in Appendix II. Also note the errors of the experiment.

PROBLEM A2.

Weight of Cement.

70. **Object.** The object of this experiment is to determine the weight of a unit volume of dry cement.

71. **Apparatus Required.** Standard sifting box.*

72. **Materials Required.** About one-half peck of each assigned cement.

73. **Method of Operation.** Place a small quantity of cement upon the sieve of the standard sifting box, and shake the sieve. Continue to add small quantities of cement and to shake the sieve until the box at the bottom is filled. When the measuring box is full remove it carefully, and strike the top of the cement level with the sides of the box by means of a straight edge. Then weigh the box together with the cement contained. Also weigh the box empty, and measure its inside dimensions.

74. Repeat the entire operation with the other assigned cement.

75. After using the cement for this experiment do not return it to the cans or bins from which it was taken, unless special instructions to that effect have been given, but place it in the waste-cement can.

76. **Report.** Compute and tabulate the weight in pounds per bushel and in pounds per cubic foot. Also state the capacity of the box.

* See Fig. 6, page 13.

PROBLEM A3.

*Specific Gravity of Cement.**

77. **Object.** The object of this experiment is to determine the specific gravity of the given samples of cement.

78. **Apparatus Required.** Le Chatelier flask with jar and small funnel,† glass rod, pipette, thermometer, small scoop, balance and set of weights, ring stand or other similar support, and apparatus for drying cement.

79. **Materials Required.** 200 grams of each assigned cement, and about one quart of benzine.

80. **Method of Operation.** Place a small quantity of each assigned cement (75 grams) on an iron plate and dry thoroughly. While these samples are drying determine the specific gravity of each cement in its undried condition.

81. Place enough water in the jar of the Le Chatelier apparatus to half fill it. Insert enough benzine‡ into the flask to bring the surface just a little above the mark below the small bulb. Place the flask in the jar of water and allow the benzine and water to attain the same temperature. Ar-

* For a discussion of the usefulness of the specific gravity test, see "The Specific Gravity of Portland Cement," by Richard K. Meade and Lester C. Hawk, Proc. Am. Soc. for Testing Materials, vol. VII, p. 363.

† See Fig. 61, page 179.

‡ See paragraph 11, page 180.

range the ring stand so that the flask will be held vertically in the jar of water and so that the small funnel will extend about an inch into the top of the flask. By means of the pipette withdraw enough benzine to bring the surface exactly to the mark below the small bulb. Weigh out 65 grams of cement, and insert it into the flask through the funnel, a little at a time, first noting the temperature of the water. A little of the cement can be taken in the scoop and can be passed through the funnel by using the glass rod. It is necessary to introduce only a small quantity of cement at a time to prevent clogging the stem of the flask near the surface of the gasoline, and also to prevent air bubbles from being carried into the liquid with the cement. When all of the cement has been inserted in the flask read the position of the surface of the gasoline and note the temperature of the water.

82. The volume between the mark below the small bulb and the zero of the graduation above the bulb is 20 c.c. The units of the graduation are cubic centimeters and the smallest divisions are tenths of centimeters. The specific gravity of the cement will be 65 divided by the volume displaced. If the temperature of the benzine has changed during the determination, a correction to the apparent displaced volume can be obtained by multiplying the total volume of benzine used, by the number of degrees change in temperature, by the coefficient of expansion of benzine. (Ben-

zine is not a very definite compound, but for the purpose of making this correction it will be sufficiently exact to use 0.0014 as the coefficient of expansion per degree centigrade.) The correction will be subtracted from the observed value of the displaced volume for an increase in temperature, and will be added for a decrease in temperature.

83. Next determine the specific gravity of each dried cement, following the instructions given in paragraph 81, and being careful to cool the cement to the temperature of the liquid before inserting it into the flask.

84. To prepare the Le Chatelier flask for the second determination, pour into the bottle marked "Used Benzine" enough of the liquid to lower the surface to a little above the mark below the small bulb, and then bring the surface exactly to the mark by means of the pipette. After completing the second determination, carefully pour into the bottle marked "Used Benzine" as much of the liquid as possible until the cement begins to pass out. Then shake the flask over the waste jar to remove the remainder of the cement and benzine. Complete the cleaning by placing a little water in the flask and shaking it into the waste jar. Rinse two or three times to remove every particle of cement.

85. Be careful not to break the flask, as it is expensive. If the flask should be broken, do not throw away the pieces until you find whether it

can be repaired, since in the latter case the charge for the breakage will probably be much less than the cost of a new flask.

86. Instead of determining the volume of a known weight of cement by inserting all of the 65 grams, the method of finding the weight of a given volume could have been used by inserting just enough cement to displace some given volume, say 20 c.c., and by reweighing the remainder of the cement. In this case the specific gravity would have been computed by dividing the weight of the cement introduced by 20.

87. Report. In the report for this problem state the apparatus by which each result was obtained. State the difficulties encountered and the precautions which should be observed. State whether the specific gravity of the liquid used affects the results, and state whether water, alcohol, kerosene, gasoline, or turpentine could be used instead of benzine. Report your results to the nearest hundredth and compare your results with the specification in Appendix II.

PROBLEM A4.

Plasticity of Cement — Boulogne Method.

88. Object. This test is for the purpose of determining the percentage of water required to produce the proper plasticity for the assigned cement paste, according to the Boulogne method.

89. Apparatus Required. Trowel, pan, beaker, graduated cylinder, and coarse balance with set of weights.

90. Materials Required. 1000 to 1500 grams of each assigned cement, and water for mixing.

91. Method of Operation. Weigh out 500 grams of cement, place it upon the mixing table, form a crater at the center of the pile, pour into the crater a known quantity of water (say 21 per cent of the weight for Portland cements, and 30 per cent for natural cements), turn the cement into the crater from the edges of the pile, and work the paste vigorously with a trowel for about five minutes. To determine whether the paste is of the proper consistency, apply the following tests: 1. The consistency of the paste should not change if gauged for an additional period of three minutes after the initial five minutes. 2. A small quantity of paste dropped from the trowel upon the mixing table from a height of 0.50 meter (20 inches) should leave the trowel clean, and should retain its form approximately without cracking. 3. A small quan-

tity of paste worked gently in the hands should be easily molded into a ball, on the surface of which water should appear. When this ball is dropped from a height of 0.50 meter (20 inches), it should retain a rounded form without cracking. 4. If a slightly smaller quantity of water be used the paste should be crumbly and should crack when dropped upon the table. On the other hand, the addition of a greater quantity of water — one or two per cent — should soften the paste, rendering it more sticky, and preventing it from retaining its form when dropped upon the table.

92. If the paste is too dry to fulfill the requirements of the tests described, add a little more water, carefully noting the amount, and repeat the tests. When the correct consistency is obtained, try a fresh sample to check the result, since some error may arise from adding water to paste which has been mixed for several minutes.

93. **Report.** In reporting this problem tabulate the results for each trial, stating the character of the paste obtained with each percentage of water. Also record the trials made with each mixture, showing the number of mixtures for each brand of cement. State the estimated error in the results as indicated by the quantity of water required to produce a noticeable change in the consistency of the paste.

PROBLEM A5.

Plasticity of Cement — with Vicat Apparatus.

94. **Object.** This test is for the purpose of determining the percentage of water required to proper plasticity for the assigned cement paste, by use of the Vicat apparatus.

95. **Apparatus Required.** Vicat machine fitted with plunger and with cap marked "Piston"; 1 vulcanite ring, 1 plate of glass about 4 inches by 4 inches, sandglass, and the apparatus required for Problem 4.

96. **Materials Required.** 2000 to 2500 grams of each assigned cement, and water for mixing.

97. **Method of Operation.** Determine the per cent of water required to make a plastic paste for each assigned cement by the Tetmajer method and by the method recommended by the American Society of Civil Engineers.

98. **Tetmajer Method.** Mix 500 grams of cement into a paste, following the method described in Problem 4, noting the per cent of water used. Place the ring of the Vicat apparatus (large end up) on a piece of plate glass, fill with the paste, and carefully smooth off the top. See that the piston of the Vicat apparatus works smoothly. Then note the reading on the scale when the plunger rests upon the surface of the glass, outside of the ring. Next bring the plunger to rest upon the

surface of the paste, then suddenly release it and allow the piston to descend of its own weight. When it finally comes to rest, note the reading on the scale. The paste is of the proper consistency if the plunger comes to rest six millimeters above the glass. If the paste is too dry add a small quantity of water; and repeat the determinations until the proper consistency is obtained. Then check the result with a fresh mixture.

99. **American Society of Civil Engineers' Method.** Weigh out 500 grams of cement, place it upon the mixing table, form a crater at the center of the pile, pour into the crater a known quantity of water, turn the dry material from the edge of the pile into the crater with a trowel, and allow the material to stand until the water has been absorbed. Complete the mixing by vigorously kneading the paste with the hands for one and one-half minutes, the process being similar to that used in kneading dough. (The sandglass is used to indicate the time of kneading.) Form the paste quickly into a ball with the hands, completing the operation by tossing it six times from one hand to the other, with the hands about six inches apart. Then press the ball into the ring through the larger opening. Place the ring upon the glass with the small end up, and smooth the surface of the paste to a level with the top of the ring. Bring the plunger of the Vicat machine to the surface of the paste, noting the reading on the scale, and release

the plunger quickly. When the plunger finally comes to rest, note the reading on the scale. The paste is of the proper consistency if the piston comes to rest 10 millimeters below the top of the ring. Repeat the trials in a similar manner, using a fresh mixture each time, until a paste is obtained which has the proper consistency.

100. **Report.** In reporting this problem follow the instructions for Problem A4, and in addition to the results for Problem A5 state the final results for Problem A4, for comparison. Also plot the results for Problem A5 upon coördinate paper, using percentage of water as abscissas and depth of penetration as ordinates. Draw a curve for the plotted values for each brand of cement.

PROBLEM A6.

Soundness of Cement — Cold-Pat Test.

101. **Object.** This test is for the purpose of determining whether the assigned cements are likely to produce cracks or disintegration in structures in which they might be used.

102. **Apparatus Required.** Trowel, pan, beaker, graduated cylinder, sandglass, coarse balance with set of weights, and eight pieces of glass each about three inches by three inches.

103. **Materials Required.** 500 grams of each assigned cement, and water for mixing.

104. **Method of Operation.** Mix 500 grams of one of the assigned cements into a plastic paste, using the per cent of water obtained in Problem 5 by the method recommended by the American Society of Civil Engineers. Make four circular pats, each having a diameter of about three inches and a thickness at the center of about one-half inch. The edges of the pat should be made as thin as possible. Stamp each pat with the number of the cement and with the number of your locker. Place the pats in the moist chamber, from which they will be removed at the end of twenty-four hours, and will be placed in pans having the same number as the locker. Fill one of these pans with water so that when removed from the moist

chamber two of the four pats will be placed in air and two in water.

105. Make four similar pats, using the other assigned brand of cement, and place them in the moist chamber beside the first four.

106. Examine the pats each week for four successive weeks, at the end of which time the problem is to be reported.

107. **Report.** In the report of this problem state the condition in which each pat was found at each examination. State whether the pats loosened from the glass, whether the pats in water appeared green, whether the pats in air developed brown spots, whether the glass was cracked by the pats in water, whether radial cracks developed near the edges of the pats, and whether the cement disintegrated. Also note any other peculiar conditions. Consult your textbooks to find the causes which are likely to produce the results mentioned, and state your opinion of the soundness of the cements tested.

PROBLEM A7.

Soundness of Cement — Accelerated Test.

108. **Object.** The purpose of this test is the same as that of Problem A6, but the activity of the chemical changes taking place within the cement while hardening is accelerated by the application of heat.

109. **Apparatus Required.** Closed vessel arranged to boil water, provided with one rack supported in the water upon which to place specimens for the boiling test, and one rack above the water level on which to place specimens to be subjected to steam bath; also the apparatus required for Problem 6.

110. **Materials Required.** 500 grams of each assigned cement, and water for mixing.

111. **Method of Operation.** Make and mark four pats of each assigned cement, following the instructions for Problem A6. Place all of the pats in the moist chamber, and allow them to remain there until the boiling and steam tests are made, which should be at the end of twenty-four hours, but which may have to be deferred until the next laboratory period. (The time at which the problem is to be completed is indicated upon the assignment sheet.) To complete the test, place enough water in the boiler to bring the surface midway between the two racks. Place two pats

of each cement in the water, and two pats of each cement on the rack above the water. Place the cover upon the boiler, and apply heat so as to raise the temperature of the water to the boiling-point in about thirty minutes. Continue the boiling until the end of the laboratory period, provided the period of boiling does not exceed three hours. Do not remove the specimens from the boiler within an hour after the application of heat is discontinued. When the pats are removed, examine them carefully for indications of unsoundness.

112. **Report.** In reporting this problem follow the instructions given for Problem A6; and if Problem A6 has been completed, compare the results of the two problems.

PROBLEM A8.

Time of Setting of Cement.

113. **Object.** This experiment is for the purpose of determining the time required for the assigned samples of cement to acquire their initial set and their final set.

114. **Apparatus Required.** Trowel, pan, beaker, graduated cylinder, Vicat apparatus with needle, two vulcanite rings, set of Gillmore wires, thermometer, sandglass, six plates of glass about three inches by three inches, moist chamber, and pan of water.

115. **Materials Required.** 600 grams of each assigned cement, and water for mixing.

116. **Method of Operation.** Weigh out 600 grams of cement, and mix into a plastic paste, using the per cent of water obtained in Problem A5 by the method recommended by the American Society of Civil Engineers. Use water having a temperature about that of the air, and record its temperature. Fill one of the rings in the same manner as in determining the per cent of water. Form the remainder of the paste into three pats. Place one of the pats in the moist chamber, one in water, and allow one to harden in air. Note the temperature of the air.

117. In the same manner as above described, make a plastic paste of the other assigned cement,

fill the second vulcanite ring, and make three pats. Allow these specimens to harden under the same conditions as the first set.

118. Examine each specimen at intervals of, say, ten minutes to see when setting begins and when it is completed. Mix the cement promptly at the beginning of the laboratory period to allow as much time as possible for setting during the period.

119. The Gillmore wires are used with the pats. When the light wire is just supported upon the surface the initial set is said to have occurred, and when the heavy wire is supported the final set is said to have occurred. Note the mark made by the thumb nail at the time of the initial set and of the final set.

120. The Vicat apparatus is used with the rings. To test one of the specimens, bring the needle to the surface of the paste and release it suddenly. The initial set is said to have occurred when the needle ceases to pass a point five millimeters above the bottom of the ring. The final set is said to have occurred when the needle ceases to penetrate the surface. (Note that the Vicat apparatus is used only with the rings, and that the Gillmore wires are used only with the pats. The two methods of determining the points at which the initial and final sets occur are arbitrary, and hence the results by the two methods need not agree.) In using the Vicat apparatus keep the needle clean and see that the slide works freely.

121. **Report.** In reporting this problem compare the results by the two methods, state conditions affecting the rate of setting in each case, and state what errors are likely to occur.

PROBLEM A9.

Tensile Strength of Neat Cement — Variation with Age.

122. **Object.** The purpose of this test is to determine the strength acquired by neat briquettes of the assigned cements in seven days and in twenty-eight days, and to determine the increase in strength during these periods.

123. **Apparatus Required.** Trowel, pan, beaker, graduated cylinder, No. 20 sieve, sandglass, thermometer, individual or gang molds for twenty briquettes, and coarse balance with set of weights.

124. **Materials Required.** 1500 grams of each assigned cement, and water for mixing.

125. **Method of Operation.** If the molds are not already cleaned and oiled, clean them by scraping off as much mortar as possible with a trowel and by removing the remainder with a wire brush. Then oil the molds with an oily rag, and also oil the top of the mixing table where the molds are to be placed. Be careful to oil the entire surface of the molds, particularly where they come in contact with the briquettes, but be careful not to use an excess of oil, since it may be injurious to the strength of the cement.

126. Screen the cement to remove the lumps, and then weigh out 1500 grams. Mix the cement into a paste, using the per cent of water which was deter-

mined in Problem 5 to produce the consistency recommended by the American Society of Civil Engineers. Record the per cent of water, the temperature of the water, and the temperature of the air. (The temperature of the water and of the air should be about 70° F. or 21° C.) Mold ten briquettes of the paste, using the method recommended by the American Society of Civil Engineers, which is given in Appendix I. Note the interval elapsing from the time of adding water until the last briquette is molded. In like manner mix the other cement and mold ten more briquettes. Mark each briquette with the number of the cement and with your own number. Do not stamp the briquette near the breaking section.

127. Cover all of the briquettes with a damp cloth, and then turn a large pan upside down over them to keep them from drying out. (If a moist chamber is provided for the purpose, place the molds in the moist chamber instead of covering as directed.) At the end of twenty-four hours the briquettes will be removed from the molds and placed in water in the storage tanks.

128. By means of a testing machine determine the tensile strength of five briquettes of each cement at the age of seven days, and of the remaining briquettes at twenty-eight days. If a shot machine is used, time the rate of flow for half a minute. If necessary adjust the rate of flow so that the force will be applied at the rate of 600 pounds per min-

ute. Be careful to center each briquette properly in the grips, and see that the bearing surfaces of the grips are free from dirt and sand.

129. Report. In the report for this problem tabulate the results, giving the per cent of water for each mixture, the time required for molding each set, the temperature of the water and the air, the brand of cement used, the age of each briquette when broken, the rate of application of the breaking load, the tensile strength of each briquette, the mean for each age, and the probable error for each mean as determined by the formula $Em = 0.6745\sqrt{\frac{\Sigma d^2}{n(n-1)}}$, in which Em is the probable error, d is the difference between any result and the mean for the set to which it belongs, and n is the number of briquettes whose results are used in computing the mean. (Note that Em is in the same units as the results, and is not per cent of error.)

130. Plot the results of the mean for each age upon coördinate paper, and connect the points by a broken line. Use the ages at which the briquettes were broken as abscissas, and the breaking strengths as ordinates. Also compare the results with the specifications in Appendix II.

PROBLEM A10.

Tensile Strength of 1:3 Mortar—Variation with Age.

131. **Object.** The purpose of this test is to determine the strength acquired by briquettes of 1:3 mortar made with the assigned cements, in seven days and in twenty-eight days, and to determine the increase in strength during these periods.

132. **Apparatus Required.** All of the apparatus required for Problem A9.

133. **Materials Required.** 400 grams of each assigned cement, 2400 grams of sand, and water for mixing.

134. **Method of Operation.** Prepare the molds as directed in Problem A9. Screen the cement through the No. 20 sieve, and weigh out 400 grams. Also weigh out 1200 grams of sand. Mix the cement and sand together dry, form a crater at the center of the pile, and pour into the crater the amount of water indicated by the table in Appendix I. Then mix into a mortar in the manner directed in Appendix I. From this mortar make and mark ten briquettes, following the directions for Problem A9. In like manner make and mark ten briquettes, using the other assigned cement. Store and test the specimens as directed in Problem A9.

135. **Report.** In the report for this problem follow the instructions given in Problem A9.

PROBLEM A11.

Variation in Tensile Strength of Neat Cement with Amount of Water.

136. **Object.** The purpose of this test is to determine the effect which a variation in the amount of water used in gauging the cement will produce upon the strength of the cement.

137. **Apparatus Required.** Trowel, pan, beaker, graduated cylinder, individual or gang molds for sixteen briquettes, No. 20 sieve, sandglass, thermometer, and coarse balance with set of weights.

138. **Materials Required.** 2400 grams of the assigned cement and water for mixing.

139. **Method of Operation.** Prepare all of the molds as directed in Problem A9. Screen all of the cement through the No. 20 sieve and weigh out 600 grams. Mix the cement into a plastic paste, using the per cent of water which was determined in Problem A5 to be required for the consistency recommended by the American Society of Civil Engineers. Record the per cent of water, and the temperature of the water and of the air. (The temperature should be about 70° F. or 21° C.) Mold four briquettes of the paste, using the method given in Appendix I. Record the interval elapsing from the time of adding water until the last briquette is molded. Mark each briquette with your

own number, and with the letter *P* to indicate that it was made with plastic paste.

140. Next weigh out 600 grams of the screened cement and mix it with water, using three per cent less water than was required for the plastic paste. Mold four briquettes from this paste, using the same method as was used for the first set. Mark the briquettes with your number, and with the letter *D* to indicate that they were made with a dry paste.

141. In like manner make four briquettes, using six per cent less water than was used for the plastic paste. Mark these briquettes with your number, and with the letters *VD* to indicate that they were made with very dry paste.

142. In like manner make four briquettes, using three per cent more water than was used for the plastic paste. Mark these briquettes with your number, and with the letter *W* to indicate that they were made with a wet paste.

143. Store the briquettes as described in paragraph 127, page 75.

144. When the briquettes are seven days old, or at the next laboratory period, remove them from the storage tank, and determine the tensile strength of each briquette by means of a testing machine. Observe the precautions given in paragraph 128, page 75.

145. **Report.** In the report for this problem tabulate the results, giving the per cent of water for

each mixture, the time required for molding each set of briquettes, the temperature of the water and of the air, the brand of cement, the age at which the briquettes were broken, the rate of application of the breaking load, the tensile strength of each briquette, the mean tensile strength for each set of briquettes, and the probable error * of the mean of each set.

146. Plot the results of the mean for each set of observations upon coördinate paper, and connect the points by a series of broken lines. Use percentages of water for abscissas, and breaking strengths for ordinates.

147. In conclusion state what is shown by your results concerning the effect of the amount of water upon the tensile strength.

* For formula for probable error, see paragraph 129, p. 76.

PROBLEM A12.

Tensile Strength of 1:3 Mortar — Effect of Different Methods of Molding.

148. Object. The purpose of this experiment is to determine the effect of different methods of molding upon the tensile strength of 1:3 mortar.

149. Apparatus Required. Trowel, pan, beaker, graduated cylinder, individual molds for twelve briquettes, No. 20 sieve, sandglass, thermometer, coarse balance with set of weights, Olsen briquette molding machine, and Böhmé hammer.

150. Materials Required. 500 grams of the assigned cement, 1500 grams of sand (be careful to use the sand which is assigned), and water for mixing.

151. Method of Operation. If the molds are not ready for use, clean and oil them as described in Problem A9. Also oil the table under the molds. Screen the cement through the No. 20 sieve to remove the lumps. Weigh out 500 grams of cement and 1500 grams of sand, and mix them together dry. Form a crater at the center of the pile, into which pour the amount of water required for the proper percentage as shown in the table on page 184. Complete the mixing by the method of the American Society of Civil Engineers as explained in Problem A5. Mold four briquettes by hand, four with the Olsen press, and four with the Böhmé hammer.

For each machine-made briquette weigh out 175 grams of mortar. Mold the briquette promptly after mixing, and keep the mortar covered with a damp cloth while molding the briquettes.

152. Record the per cent of water used, the temperature of the water and of the air, and the interval from the time of adding the water until beginning to mold the first briquette, and until the completion of molding the last briquette.

153. Mark the briquettes, using your own number and the letters *H*, *O*, and *B* for hand-made briquettes, Olsen-press briquettes, and Böhmé-hammer briquettes, respectively. Store the briquettes as directed in Problem A9, and break them at the age of seven days or at the next laboratory period.

154. **Report.** In the report for this problem tabulate the results, giving all of the observed data and results. State the tensile strength of each briquette, the mean for each set, and the probable error* for each mean. Compare the strength of these briquettes with the strength of the neat cement briquettes made from the same brand of cement in Problem A9. Also compare the results of this problem with the specifications given in Appendix II.

* For formula for probable error, see paragraph 129, p. 76.

PROBLEM A13.

Comparison of Different Methods of Hand Molding.

155. **Object.** The object of this experiment is to determine the effect of different methods of molding upon the tensile strength of neat cement.

156. **Apparatus Required.** Trowel, pan, beaker, graduated cylinder, individual or gang molds for sixteen briquettes, No. 20 sieve, sandglass, thermometer, and coarse balance with set of weights.

157. **Materials Required.** 3000 grams of the assigned cement, and water for mixing.

158. **Method of Operation.** If the molds are not ready for use, clean and oil them as directed in Problem A9. Weigh out 1500 grams of screened cement and mix into a paste, using three per cent less water than was required for the plastic paste in Problem A5 by the method of the American Society of Civil Engineers. Make five briquettes in each of the following ways: (1) by entirely filling the molds, pressing the mortar into place with the thumbs, and troweling the surface; (2) by partially filling the mold and pressing the paste into place after the addition of each increment; (3) by partially filling the mold and ramming each increment with an oak rammer having a cross section of about three-fourths inch by three-fourths inch, and having a length of twelve inches; (4) by using a half-inch round iron or brass rammer, about twelve inches

long. (In using a rammer, the compression should be produced by the blow of rod, and not by pushing the rammer into the paste.) Be careful to avoid injuring the edges of the molds.

159. Mark each briquette with your number, and in addition mark the first five with 1, the second five with 2, etc. Store the briquettes as directed in Problem A9, and break at the age of seven days or at the next laboratory period.

160. Record the per cent of water used, the temperature of the water and of the air, the time from adding the water until beginning to mold the first briquette, and until the completion of molding the last briquette for each mixture.

161. Report. In the report for this problem tabulate the results, giving all of the observed data. State the tensile strength of each briquette, the mean for each set, and the probable error * for each mean.

* For formula for probable error, see paragraph 129, p. 76.

PROBLEM A14.

Compressive Strength of Cement and Cement Mortar.

162. **Object.** This experiment is for the purpose of determining the compressive strength of the assigned cements.

163. **Apparatus Required.** Trowel, pan, beaker, graduated cylinder, No. 20 sieve, sandglass, thermometer, six molds for one-inch cubes, six molds for two-inch cubes, and coarse balance with set of weights.

164. **Materials Required.** 1000 grams of the assigned cement, 1200 grams of sand, and water for mixing.

165. **Method of Operation.** If the molds are not ready for use, clean and oil them as directed in Problem A9. Weigh out 600 grams of cement and mix into a paste, using the per cent of water determined in Problem A5 by the method of the American Society of Civil Engineers. Fill the one-inch molds with the paste.

166. Weigh out 400 grams of cement and 1200 grams of sand, and mix into a mortar as directed in Appendix I. Fill the two-inch molds, pressing the mortar into the molds with the thumbs.

167. Mark all of the specimens with your number, and store them as directed in Problem A9. Break three of the small cubes and three of the large

cubes at the end of one week, and the others at the end of four weeks.

168. Report. In the report for this problem tabulate the data and the results, giving the strength of each specimen, the mean of each set for each age, and the probable error * of each mean. Compare the compressive strength with the tensile strength obtained in previous problems.

* For formula for probable error, see paragraph 129, p. 76.

CHAPTER IV.

TESTS OF CONCRETE.

PROBLEM B1.

Preparation of Specimens.

169. **Object.** This assignment is for the purpose of preparing specimens to be used, for subsequent problems, in determining the compressive strength, the shearing strength, the flexural strength, and the modulus of elasticity of concrete.

170. **Apparatus Required.** A sufficient number of molds for six-inch cubes to make three cubes of each mixture for each age at which tests are to be made; a sufficient number of molds for eight-inch cylindrical or six-inch square prisms, eighteen inches long, to prepare one prism for each age; a sufficient number of molds for shear specimens * to prepare three specimens of each mixture for each age; a sufficient number of molds for bond specimens to prepare three specimens with each kind of reinforcement for each age, for pulling out tests, and an equal number for bond tests with beam specimens;† a

* For description of molds see page 94.

† For a description of specimens for bond tests see page 97. For the pulling-out test the specimens may be made in molds for

number of molds for beams* and for columns to prepare as many specimens of each as desired; a mixing platform; shovels, trowels, and a measuring box for sand and one for stone.†

171. **Materials Required.** Cement, sand or fine gravel, crushed rock which will pass a 1-inch ring, water, building paper, two 10-inch rings of ¼-inch square reinforcing steel with ends lapping 6 inches for each reinforced shear specimen, reinforcing bars for concrete beams, and reinforcing bars and hoops for concrete columns.

172. **Method of Operation.** See that the molds to be used are clean. If the molds are in pieces put them together, and place all molds which are without bottoms on a reasonably smooth floor, with a layer of building paper under the molds. The molds should be placed in such positions that they will not have to be disturbed until the concrete has set. Near the end of each mold for beams, attach a small wooden block to the side of the mold in such a position that it will be cast in the beam at the center of the depth and exactly over the point at which the support is to be placed when the beam is tested.

either cubes, prisms, or cylinders, provided the length of steel embedded is at least six inches and preferably not over twelve inches. For beam specimens for bond tests ordinary beam molds can be used by inserting a board partition at the middle of the beam, allowing the steel to pass through the board.

* See page 23.

† If the ratio of stone to sand to be used is an integer only one measuring box will be required.

173. Place the measuring box upon the platform and fill it level full with sand or fine gravel. If a large batch of concrete is required, move the measuring box and refill it with sand. When a sufficient amount of sand has been thus deposited upon the platform, level the top of the pile and place upon the sand the required quantity of cement.* Mix the cement and sand together dry. Level the top of the pile and place upon it the required amount of stone. In order that the measurement of the stone may be carefully made it is better to place the measuring box on the platform, beside the sand and cement, instead of placing it on top of the pile. After placing the stone upon the sand and cement, turn the mixture dry at least twice, and then while adding water turn the concrete a sufficient number of times to produce a uniform mixture. If so instructed, measure the quantity of water used.

174. After the concrete has been thoroughly mixed fill all of the molds which are to be used for that mixture, puddling the concrete with a stick or rod. Insert steel for reinforcement as directed. In finishing the top surfaces of the specimens see that the concrete is left smooth, but do not trowel the top unless so instructed. Mark upon each specimen the squad number or letter, the consecu-

* If enough specimens are to be molded to require the use of one or more sacks of cement, it will be convenient to use a measuring box of the proper size to require one sack of cement to one box of sand. One sack of cement may usually be taken as one cubic foot. This is not exact but corresponds well with practice.

tive number of the batch, and with the year, *e.g.*, B—8—11 would signify that the specimen was one of batch number 8, made by squad B in 1911. If specimens are made using different kinds and amounts of reinforcement, the batch number can be modified, *e.g.*, 8*a* might refer to one type of the specimens made from batch number 8.

175. After the concrete has set for at least two days the molds can be removed, and the specimens can be placed in suitable places for storage. If the specimens are to be stored in air the concrete should be flooded with water every day for one week after being molded.

176. **Report.** Tabulate the data obtained, stating the brand of cement used, the character and size of the sand or gravel and of the stone, the proportions of the ingredients in the concrete, the character of the mixture, the kind and amount of steel placed in each specimen, the number of specimens of each kind, the markings on each specimen, the date at which each specimen is to be tested, and the place and method of storage for each specimen.

PROBLEM B2.

Compression Test of Concrete.

177. **Object.** This test is for the purpose of determining the crushing strength of concrete.

178. **Apparatus Required.** A 100,000-pound or 200,000-pound testing machine, equipped with a compression head; and a measuring scale or rule.

179. **Materials Required.** Three 6-inch concrete cubes for each mixture to be tested, building paper, and plaster of Paris.

180. **Method of Operation.** Place a piece of building paper upon the table of the testing machine. Coat one face of the first cube to be tested with plaster of Paris, and place the cube in the machine with the coated face down. Coat the top face with plaster of Paris and place a piece of building paper between the cube and compression head of the machine. Run the compression head down until it is in contact with the cube and apply a load of not more than 5000 pounds. Allow this load to remain for a few minutes while the plaster of Paris is setting.* Then apply the load using the slow motion. Record the maximum load, the character of failure, and any other observations of interest or importance. Test each cube in a similar manner.

* In case no plaster of Paris is available fair results may be obtained by using two or three layers of building paper above and below the cube.

181. Report. Tabulate the results giving all of the data, for the specimens tested, which were obtained at the time the concrete was made, and in addition tabulate the results of the test, stating the dimensions, the bearing area, the total maximum load, and the unit-crushing strength of each specimen, the average strength for each mixture, and the probable error of each mean.* Compare your results with the values of crushing strength given in the textbooks, reporting the values found and the authority.

* See page 76 for formula for probable error.

PROBLEM B3.

Shearing Test of Concrete.

182. **Object.** This experiment is for the purpose of determining the shearing strength of concrete.

183. **Discussion.** A considerable number of forms of specimens have been used for the purpose of making shear tests of concrete, but some objection can be found to all of which the writer has knowledge. The practical necessity of using a specimen of considerable thickness makes it almost impossible to avoid a slight uncertainty in the results on account of other stresses which are produced, in addition to the shearing stresses. Two common forms of specimens which have been used are (*a*) short beams and (*b*) plates for punching tests.* The forms of specimens used for punching tests by Professor A. N. Talbot, of the University of Illinois, are shown in Fig. 49. The form of test piece used by the author consists of a flat plate 12 inches square by 3 inches in thickness with eight holes, $\frac{3}{4}$-inch diameter, arranged along the circumference of a 5-inch circle. These test pieces can be made either with or without steel reinforcement outside of the circle of holes. The test piece without reinforcement is shown in Fig. 50.

* For the results obtained with different forms of specimens see Bulletin No. 8 of the University of Illinois Engineering Experiment Station.

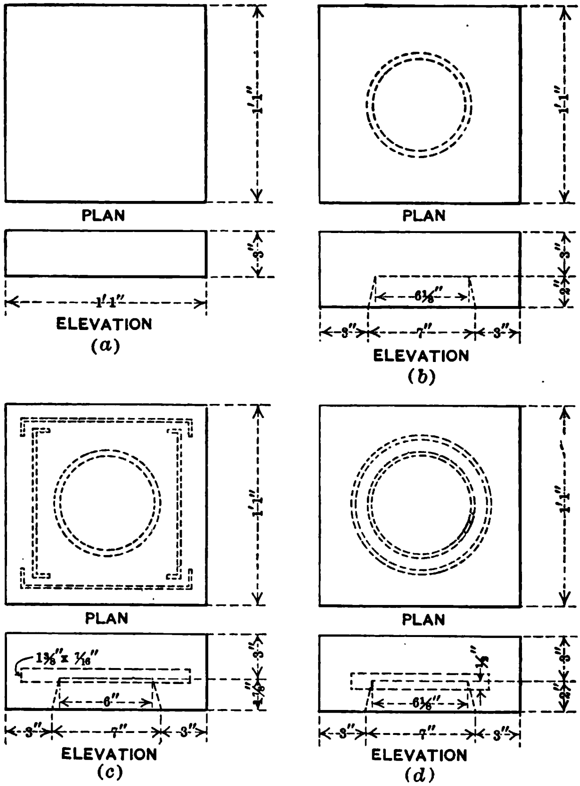

Fig. 49. — Forms of Shear Test Piece used by Professor A. N. Talbot. (*a*) Plate. (*b*) Recessed Block. (*c*) and (*d*) Reinforced Recessed Blocks

184. The forms required for specimens similar to that shown in Fig. 50 consist of a bottom board 2 inches in thickness, with holes in which to insert the pins which form the holes in the test piece, and four side pieces connected by the use of three

hinges and one hinge hasp. The pins are allowed to soak in water over night, before using, so that when the concrete has hardened the pins can be easily removed from the specimen.

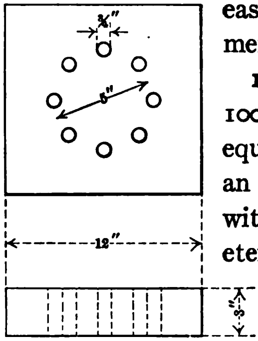

Fig. 50. — Concrete Specimen for Shearing Test

185. Apparatus Required. A 100,000-pound testing machine equipped with compression head, an oak or iron bearing block with a hole 6 inches in diameter, a cylindrical iron block 5 inches in diameter, to be used as a punch, and a rule or measuring scale.

186. Materials Required. Three specimens for each mixture to be tested, building paper, some plaster of Paris.

187. Method of Operation.* Cut pieces of building paper 12 inches square, and from the center of each piece cut a circular piece 6 inches in diameter. Trim each circular piece to a diameter of 5 inches. Place the bearing block upon the table of the testing machine and place upon it one of the large pieces of paper. Place one specimen in position on the paper, embedding it in plaster of Paris, and place one of the circular pieces of paper upon the top of the central portion of the specimen with a layer of plaster of Paris between the paper and the

* These instructions apply particularly to tests to be made using perforated test pieces, similar to the form shown in Fig. 50.

specimen. On top of the paper place the iron punching block and apply the load, using the slowest speed. Record the ultimate load, the method of failure, and any other observations of interest. Test each specimen in a similar manner.

188. Report. Tabulate the results giving all of the data, for the specimens tested, which were obtained when the concrete was made, and in addition give the dimensions, shearing area, total load, and unit shear for each specimen, the mean unit shear for each mixture, and the probable error for each mean.* Compare your results with the values of shearing strength given in the textbooks, reporting the values found and the authority.

* For the formula for probable error see page 76.

PROBLEM B4.

Test of Bond of Steel Embedded in Concrete.

189. Object. The object of this experiment is to determine the ultimate strength of the bond existing between steel and concrete, for bars embedded in concrete.

190. Discussion. The first tests of the strength of the bond between steel and concrete were made by pulling out steel bars which were embedded in cylinders of concrete.* Later tests which have been made, using beams or specimens in which the conditions of molding and of loading were similar to those for bars in beams and slabs, indicate that the first methods employed give results which are much higher than can be expected for the conditions which would govern the design of the majority of reinforced concrete structures.† In this experiment both methods are to be used, the method used for the beam specimens being that described by Mr. H. C. Berry, in Vol. IX of the Proceedings of the American Society for Testing Materials, pages 495–501.

* For results by this method see Bulletin No. 8 of the University of Illinois Engineering Experiment Station.

† For results of tests by both methods see "Tests of Bond in Reinforced Concrete Beams," by Morton O. Withey, Proceedings of the American Society for Testing Materials, Vol. VIII, pages 469 to 479; and "Some Tests of Bond of Steel Bars Embedded in Concrete by Three Methods," by H. C. Berry, Proceedings of the American Society for Testing Materials, Vol. IX, pages 495 to 501.

191. Apparatus Required. A 100,000-pound testing machine with V-block and with wings for supporting beams;* two rocker or roller supports; two rollers $1\frac{1}{4}$ or $1\frac{1}{2}$ inches in diameter, to be placed on top of specimens; four pieces of steel plate, to be used at points of bearing against the concrete; a small I-beam or piece of steel rail, 2 feet long; a plate approximately 6 inches in diameter, with a hole at the center to be used as a bearing plate for the pulling tests; two steel bars $2\frac{1}{2}$ by $\frac{3}{8}$ inches and as long as the beam specimens are wide, with a groove in each milled to the slope of a taper pin and extending from each end toward the center of one face of each bar; two taper pins, to be used with the bars above described as a hinge; and a good rule for measuring specimens and locating bearing points.

192. Materials Required. Three specimens for pulling tests, for each mixture to be tested, three beam† specimens for each mixture of concrete, and plaster of Paris.

193. Method of Operation. Remove the grips from the fixed head of the testing machine, and place the bearing plate in position, on top of the fixed head. Place the specimen in position on the bearing plate, as shown in Fig. 51, placing a layer

* For machines not equipped with wings, supports for beams may be made by placing steel beams or rails upon the table of the machine.

† Beam specimens should have each portion reinforced to prevent failure by diagonal tension.

of building paper between the specimen and the plate, with a layer of plaster of Paris between the paper and the specimen. Fasten the rod of the specimen in the grips of the movable head, and apply a load of 500 pounds. Allow this load to remain for a few minutes while the plaster of Paris is setting, and then continue to apply the load. Record the ultimate load and the method of failure. Test each specimen for the pulling test in a similar manner.

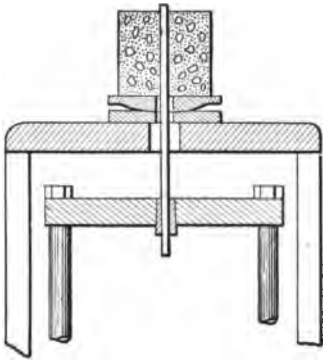

Fig. 51.—Arrangement for Pulling Out Test

194. Remove the grips from the movable head of the testing machine and attach the V-block. Place one of the beam specimens in position, as shown in Fig. 52. Between each roller or rocker and the concrete, place a flat plate, with a layer of plaster of Paris between the steel and the concrete. See that the points of bearing, both for the load and for the supports, are symmetrical with respect to the V-block and to the point of division of the beam. See that the taper pins are snugly inserted between their bearing plates. Measure and record the length of span, the distance between points of loading, and the distance from center of steel to

center of bearing pins. Apply the load slowly, observing the deflection. If the deflection becomes excessive, remove the load and tighten the taper pins. Record the maximum load and any

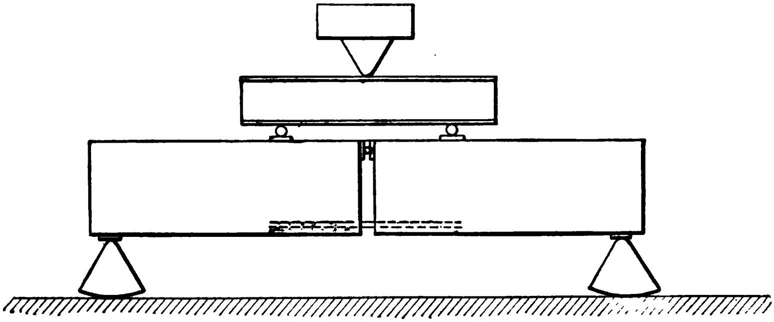

Fig. 52. — Arrangement of Beam Specimen for Test of Bond

observations which may be of interest. Test the remaining specimens in a similar manner.

195. Report. Tabulate the results giving all of the data, for the specimens tested, which were obtained when the specimens were made, and in addition give the dimensions, length of span, method of loading, moment arm of steel, total load, total stress on steel and ultimate bond stress per square inch of surface of embedded steel, for each specimen, the mean unit bond stress for each mixture, and the probable error for each mean.*

Compare your results with the values of bond strength given in the textbooks, reporting the values found and the authority.

* For the formula for probable error, see page 76.

PROBLEM B5.

Modulus of Elasticity of Concrete.

196. Object. The object of this experiment is to determine the coefficient of elasticity of concrete.

197. Apparatus Required. A 100,000 or 200,000-pound testing machine, and compression micrometer or deformeter adapted to the specimens to be used.

198. Materials Required. One or more 8-inch cylindrical or 6-inch square concrete prisms 18 inches in length, building paper, and plaster of Paris.

199. Method of Operation. Attach the deformeter to the prism. Coat each end of one prism with a layer of plaster of Paris, and place the prism on end upon the platform of the testing machine, with a layer of building paper at the top and bottom. Run the movable head of the machine down until it is in contact with the specimen. Read the micrometers and record the readings. Apply a load of 2000 pounds and allow the specimen to stand with the load applied, while the plaster of Paris is setting. Read the micrometers while the load of 2000 pounds is applied and record the readings. Apply the load in increments of 2000 pounds, noting the micrometer readings for each increment. Proceed in this manner until the load amounts to a little less than the estimated ultimate

load. Then remove the deformeter and continue the application of the load until the concrete fails, recording the maximum load, the method of failure, and any other observations of interest. Test each prism in a similar manner.

200. Report. Tabulate all of the data for the specimens tested which were obtained at the time the specimens were made, and in addition tabulate the data obtained during the test, giving the amount of each load for which readings were taken, the readings observed, the total deformation, the unit stress, the unit deformation, the total maximum load, the crushing strength, and the coefficient of elasticity for values of the unit stress equal to 500 pounds per square inch, 1000 pounds per square inch, and 1500 pounds per square inch. Also record the dimensions of the specimen and the length between contact points. Plot the stress-deformation diagram upon coördinate paper, showing each point observed.

PROBLEM B6.

Cross Breaking Test of Concrete Beams.

201. **Object.** The purpose of this experiment is to determine the flexural strength, stiffness, and method of failure of plain and reinforced concrete beams.

202. **Apparatus Required.** A 100,000-pound testing machine with V-block and with wings for supporting beams,* rocker or roller supports, three pieces of steel plate to be used at bearing points of the beam, a strip of mirrored glass with a graduated scale or rule attached, and a piece of thread or fine wire.

203. **Materials Required.** As many plain and reinforced concrete beams as desired, and some plaster of Paris.

204. **Method of Operation.** Set the rocker or roller supports at the desired distance apart and at equal distances on either side of the point of application of the load. Set one beam upon the supports, placing a steel plate between each roller or rocker and the concrete, with a layer of plaster of Paris between each plate and the concrete. In like manner place a plate upon the top of the beam, at the point of bearing of the V-block. At the center of the side of the beam attach the mirror

* For machines not equipped with wings, supports for beam tests may be made by placing steel beams or rails upon the table of the machine.

and scale in a vertical position. Drive a nail in the wooden block cast in the side of the beam over each support. Stretch a thread or wire from one nail to the other, allowing it to pass in front of the mirror and scale, and over one nail to a weight. Stand in front of the mirror, bring the eye to such a level that the thread and its image are in line, and note the reading of the thread on the scale. Balance the scale beam of the machine and run the movable head of the machine down until the V-block is in contact with the steel plate on top of the beam. Apply the load in increments of not more than one-tenth of the estimated ultimate load, recording the amount of the load and the reading of scale on the side of the beam, for each increment. Note the load at which the first crack appears, the method of failure, and the maximum load. Record the length of span. Test the remaining beams in a similar manner.

205. **Report.** Tabulate all of the data, for the specimens tested, which were obtained at the time the specimens were made, and in addition tabulate the data obtained at the time of the test, including the amount of load for each reading, the readings observed, the amount of deflection, the computed values of the stress in the concrete and in the steel. Also, under remarks and opposite the proper loadings, record the appearance of cracks and similar remarks concerning the method of failure. Plot a curve of the deflections upon coördinate paper.

PROBLEM B7.

Deformation of Concrete Beams.

206. **Object.** This experiment is for the purpose of determining the flexural strength, the stiffness, the fiber deformation, and the method of failure of plain and reinforced concrete beams.

207. **Apparatus Required.** A 100,000-pound testing machine with V-block and with wings for supporting beams, a steel I-beam longer than one-third the length of the beam, rocker or roller supports, two pieces of steel shafting $1\frac{1}{2}$ inches in diameter, four pieces of steel plate, deformeter similar to Fig. 45 or Fig. 46, pages 51–52, a strip of mirrored glass with scale or rule attached, and some thread or fine wire.

208. **Materials Required.** As many plain and reinforced concrete beams as desired and some plaster of Paris.

209. **Method of Operation.** Set the supports at the desired distance apart and at equal distances on each side of the V-block. Place one beam on the supports, with a steel plate embedded in plaster of Paris, between each plate and the beam. In a similar manner embed two plates in plaster of Paris on the top of the beam, and at distances from each support equal to one-third of the length of span. Place one piece of steel shafting on each plate and upon these rollers place the I-beam in position, so

that the V-block will bear upon the center of the I-beam and the latter will transfer the load to the two points on the beam. Attach the frames of the deformeter to the beam, placing each frame as near the points of loading as possible. Measure carefully the distance between the two frames and also the position of the points of contact of each frame. At the center of one side of the beam attach the mirror and scale in a vertical position. Drive a nail in the wooden block in the side of the beam over each support. Stretch a thread or fine wire between the two nails, allowing it to pass in front of the mirror and scale and over one nail to a weight. Stand in front of the mirror, bring the eye to such a level that the thread and its image are in line, and note the reading of the thread on the scale. Balance the scale beam of the machine and read the micrometers or dials of the deformeter. Apply the load in increments of not more than one-tenth of the estimated ultimate load. Record the distance between supports, the position of the bearing points, the amount of the load for each reading, the readings of the deformeter, the readings of the mirror scale, the load at which the first crack appears, the method of failure, and the maximum load. Test the remaining beams in a similar manner.

210. **Report.** Tabulate all of the data, for the specimens tested, which were obtained at the time the specimens were made, and all of the data which were obtained at the time of the test. State the

amount of the deflection and the deformation for each reading, the unit stress in the concrete and in the steel for the load at which the first crack appeared and for the maximum load, as determined both from the deformation and by computation from the load. Plot curves of the deflections, the deformations, and the position of the neutral axis.

PROBLEM B8.

Test of Concrete Columns.

211. **Object.** This experiment is for the purpose of determining the ultimate strength of plain and reinforced concrete columns.

212. **Apparatus Required.** A testing machine suitable for long vertical specimens with a capacity of not less than 100,000 pounds, deformeter similar to Fig. 45 or Fig. 46, pages 51–52, two strips of mirrored glass with a scale or rule attached to each, some thread or fine wire, and two plumb bobs.

213. **Materials Required.** As many plain and reinforced concrete columns as desired, building paper, and plaster of Paris.

214. **Method of Operation.** Place one column on the table of the testing machine, with a layer of building paper under the column, and a layer of plaster of Paris between the concrete and the paper. See that the scale beam of the machine is balanced for zero load. Attach one of the frames of the deformeter to the column near the upper end and attach the other frame near the lower end. Measure carefully the distance between frames and the position of the points of contact. Read each micrometer or dial. Coat the upper end of the column with plaster of Paris, on top of which place a layer of building paper. Then run the movable head of the machine down until the com-

pression face is in contact with the paper. Apply a small load and allow the machine to stand thus while the plaster of Paris is setting. Near the upper end of each of two faces of the column, at right angles to each other, attach a piece of thread or fine wire. To the lower end of each thread or wire attach a plumb bob. Near the center of each of the two faces of the column attach a mirror and scale to the concrete, so that the scale can be used to measure the deflection of the column. Bring the eye into line with one plumb line and its reflection in the mirror, and note the reading on the scale. Read the other scale in like manner. Apply the load in increments of not more than one-tenth of the estimated ultimate load, observing for each increment the readings of the deformeter and of the plumb lines. Note the load at which the first crack appears, the maximum load, and the method of failure. Test the remaining columns in a similar manner.

215. **Report.** Tabulate all of the data, for the specimens tested, which were obtained at the time the columns were cast; and in addition tabulate the data and results obtained at the time of the test; including the observed readings, the load for each set of readings, the average unit stress, the deformation, and the deflection. For reinforced columns determine the stress in the concrete and in the steel, as shown by the deformation. Plot curves of the deflection and deformation.

CHAPTER V.

TESTS OF IRON AND STEEL.

PROBLEM C1.

Tensile Test of Wrought Iron and Steel.

216. **Object.** This experiment is for the purpose of determining the ultimate tensile strength, the yield point, the ultimate elongation, and the reduction in area of the specimens tested.

217. **Apparatus Required.** A 100,000-pound testing machine with flat grips, for specimens cut from steel plates, and with notched grips, for round specimens; a micrometer caliper; a laying-off gauge or scale; and a center punch or a scriber.

218. **Materials Required.** A number of round and flat specimens of wrought iron and steel.

219. **Method of Operation.** Measure and record the cross section of each specimen, taking the measurements with a micrometer caliper. Measure each specimen at several points using the mean value of the area of section. Record the kind of material for each specimen, if known. With the laying-off gauge mark a length of 8 inches on each specimen, dividing this length into 1-inch spaces. Place one specimen in the machine,

observing the instructions given on page 3. Start the machine, using a medium speed for the test. Keep the scale beam carefully balanced. When the yield point* of the material is reached the scale beam will drop momentarily, at which point the load should be noted and recorded. As the load increases the beam will again rise and the beam should be kept balanced until the maximum load is reached. Record the maximum load, and remove the broken specimen from the machine. Measure and record the reduced diameter or section and the length between gauge marks. Observe and record the character of fracture. Test each specimen in a similar manner.

220. Report. Tabulate the data and the results, giving the kind of material, the dimensions, the area of cross section, the maximum load, the ultimate strength, the total load at the yield point, the unit stress at the yield point, the gauge length, the amount of elongation, the percentage of elongation, the reduced cross section, the reduction in area, the percentage of reduction in area, the character of fracture, and any observations noted, for each specimen. State the average values of the ultimate strength and of the unit stress at the yield point, for each kind of material used, and the probable error of each mean, as determined by the formula on page 76.

* No yield point will be observed for specimens of hard steel.

PROBLEM C2.

Modulus of Elasticity of Iron and Steel.

221. Object. This experiment is for the purpose of determining the coefficient of elasticity of wrought iron and steel and the elastic limit of each in tension.

222. Apparatus Required. A 100,000-pound testing machine, with notched grips for holding round specimens, a duplex micrometer extensometer with electric battery and bell, or a dial extensometer, and a micrometer caliper.

223. Materials Required. One or more specimens of each kind of material to be tested. The test pieces for this experiment should be turned specimens having a diameter of $\frac{3}{4}$ inch or $\frac{7}{8}$ inch for a length of at least 9 inches, with enlarged ends. Each end should have a gripping length of at least 4 inches. A gauge length of 8 inches should be marked upon the central portion of the specimen.*

224. Method of Operation. Measure the diameter of each specimen at several points, using the micrometer caliper, and record the mean value for each specimen. Insert one specimen in the machine and attach the extensometer. Connect the electric battery and bell, if they are required. Observe and record the reading of each micrometer or dial.

* The specimens can be easily marked while in the lathe at the time they are turned.

Apply the load slowly in increments of 500 pounds, taking the readings of the extensometer for each increment. Compute the probable value of the maximum load, and when five-sixths of this amount has been applied remove the extensometer. Then continue the application of the load until the specimen breaks. Record all the data obtained. Test the remaining specimens in a similar manner.

225. **Report.** Tabulate the data and results, giving the kind of steel, the original diameter of each specimen, the area of cross section, the amount of the load for each reading, the maximum load, the unit stress corresponding to each load, all of the readings of each dial or micrometer, the total amount of elongation for each set of readings, for each dial or micrometer, the average elongation for each set of readings, the values of average unit elongation, and the values of the coefficient of elasticity obtained by dividing values of the unit stress less than the elastic limit by corresponding values of unit deformation. To determine the elastic limit of each specimen plot the stress-deformation curve and note the point at which it ceases to be a straight line. Hand in the curves with your results. Compare your results with the values given in your textbooks, stating the values found for the coefficient of elasticity and the elastic limit, and state the authority in each case.

PROBLEM C3.

Shearing Test of Steel.

226. Object. This experiment is for the purpose of determining the shearing strength of steel rivets.

227. Apparatus Required. A testing machine with flat grips, and two shearing devices similar to those shown in Fig. 53, and a micrometer caliper.

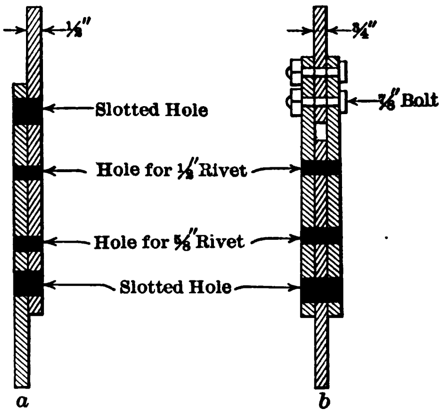

Fig. 53. — Shearing Devices

Each shearing device should be provided with bolts for the slotted holes.

228. Materials Required. Rivets of the proper size to fit the shearing devices to be used.

229. Method of Operation. Measure the thickness of the parts of each shearing device. Try a

rivet in the proper hole and mark the position of the shearing section. Remove the rivet and measure the diameter of the marked section, with a micrometer caliper. Place the rivet snugly in position, having the parts of the shearing device held together by bolts in the slotted holes. Place the ends of the shearing device in the grips of the testing machine and tighten the grips. Apply the load using the slow motion. Record the maximum load. Test at least five rivets in single shear and an equal number in double shear.

230. **Report.** Tabulate the data and results, for single shear and for double shear, stating the kind of steel, the diameter of rivet, the area of cross section, the maximum load, and the unit shear for each specimen. Also, record the average unit shear for each kind of steel tested, and the probable error of each mean as given by the formula on page 76.

PROBLEM C4.

Cold Bend Test of Iron and Steel.

231. **Object.** The purpose of this experiment is to illustrate the difference in ductility of different kinds of iron and steel, as exhibited by the cold bend test.

232. **Apparatus Required.** Anvil * and sledge.

233. **Materials Required.** Specimens of wrought iron, soft steel, and medium steel, in the form of either bars or plates.

234. **Method of Operation.** Bend the specimens in such a manner that the wrought iron and soft steel shall be bent 180 degrees, flat upon itself, and so that the medium steel shall be bent 180 degrees to a radius equal to the thickness of the material. Examine the bent specimens for cracks or signs of failure.

235. **Report.** Record the results and observations of the test, and give the requirements of the specifications of the American Society for Testing Materials, stating whether the specifications have been fulfilled in each case.

* A heavy iron block with holes of proper size at various inclinations is a more convenient device than an ordinary anvil, or specimens may be bent by steady pressure in a testing machine.

PROBLEM C5.

Torsion Test of Steel.

236. Object. This experiment is for the purpose of determining the coefficient of elasticity of steel in shear, the elastic limit of steel in shear, and the torsional modulus of rupture of steel.

237. Apparatus Required. Torsional testing machine with arm and graduated arc for measuring the angle of twist, and a micrometer caliper.

238. Materials Required. One or more pieces of steel shafting or round steel bar of suitable size for the testing machine.

239. Method of Operation. Place the specimen in the machine and adjust the indicator for reading the angle of twist. Measure the diameter of the specimen at a number of points, with the micrometer caliper, and record the results. Also, measure the length of the specimen. Apply the load slowly, reading and recording the angle of twist for successive increments of the load. Continue thus until the specimen fails, noting the maximum twisting moment. Test the remaining specimens in a similar manner.

240. Report. Tabulate the data and results, stating the kind of steel, length of specimen, diameter of specimen, the polar moment of inertia of the cross section, the value of the moment of inertia

divided by the radius of the shaft, the unit stress* for each reading, the maximum stress, the total twist for each reading, the twist per unit length, the unit detrusion† at the circumference of the shaft, and the coefficient of elasticity‡ for shear for value of the unit stress within the elastic limit. Plot the values of the unit shear and unit detrusion upon coördinate paper, from which the elastic limit can be determined. Record the value of the elastic limit thus obtained.

* If M is the twisting moment in pound-inches, I_0 the polar moment of inertia, R the radius of the shaft, and S the unit shearing stress, then for a circular section, $S = \frac{MR}{I_0}$, which is strictly correct only within the elastic limit.

† Obtained by multiplying the twist per unit length by $\frac{\pi R}{180}$.

‡ The coefficient of elasticity is equal to the unit stress divided by the unit detrusion.

PROBLEM C6.

Transverse Test of Cast Iron.

241. **Object.** This test is for the purpose of determining the flexural strength and the coefficient of elasticity of cast iron.

242. **Apparatus Required.** A testing machine with a V-block attached to the movable head, rocker or roller supports for short beams, calipers for measuring the specimens, and a deflection indicator similar to Fig. 47, page 53.

243. **Materials Required.** Three or more specimens of cast iron $1\frac{1}{4}$ inches in diameter by 18 inches in length, and three or more specimens 1 inch by 2 inches by 18 inches.

244. **Method of Operation.** Adjust the supports making the length of span 16 inches, and noting that the supports are symmetrical with respect to the V-block of the movable head. Measure and record the cross section of each specimen. Place one of the specimens in position on the supports, run the movable head of the machine down until the bearing block is in contact with the specimen, and place the deflection indicator in position, with the contact point touching the bearing block.* Adjust the indicator to read zero, and apply the load in increments, reading and recording the

* Do not place the indicator under the specimen or it may be injured when the specimen breaks.

amount of each load and the deflection. Continue thus until the specimen breaks, observing the maximum load. Test each specimen in a similar manner.

245. **Report.** Tabulate the data and the results, stating the dimensions of each specimen, the length of span, the total load for each reading, the unit flexural stress for each load, the deflection for each load, and the coefficient of elasticity for each specimen. Compute the mean values of the modulus of rupture and of the coefficient of elasticity for the round specimens and for the rectangular specimens.

PROBLEM C7.

Impact Test of Iron or Steel.

246. **Object.** This experiment is for the purpose of determining the flexural stress at the elastic limit, the modulus of elasticity, and the modulus of resilience of the materials tested, when subjected to suddenly applied loads, and for the purpose of exhibiting the behavior and method of failure of the given materials under such loads.

247. **Apparatus Required.** A Turner impact testing machine,* similar to Fig. 33, page 40, with drum for making autographic records of the deflection, and with supports for transverse specimens; a micrometer caliper; and a rule.

248. **Materials Required.** A number of specimens of each kind of material to be tested, in the form of beams from 3 to 4 feet in length, and paper for the recording drum.

249. **Method of Operation.** Attach the paper to the recording drum and see that the stylus of the tuning fork is properly adjusted. Measure the dimensions of one beam with the caliper, place the specimen on the supports, and clamp it in place. Measure the length of span and see that the point of impact of the hammer is at the center of span. Bring the hammer into position so that it just

* For a description of this machine, see the Proceedings of the American Society for Testing Materials, Vol. VI, page 462.

touches the surface of the specimen, see that the pencil is touching the paper on the drum, and revolve the drum to mark upon the record the datum line. Then permit the weight of the hammer to rest upon the beam, and record the static deflection. Raise the hammer a short distance and allow it to fall upon the specimen. Before the hammer drops, strike the tuning fork to cause it to vibrate, and as the hammer falls rotate the drum slowly, continuing the rotation until the vibration of the specimen ceases. Record height of drop, and mark the graph obtained to indicate the number of the blow. In like manner continue to deliver blows upon the specimen, using increasing heights of fall, until the specimen breaks. For each trial measure the deflection, the rebound, and the permanent set. Record the weight used. Test the remaining specimens in a similar manner.

250. Report. Tabulate all of the data and observations, and the computed values of the fiber stress at the elastic limit,* the modulus of elasticity,† and the modulus of resilience.‡ For each speci-

* $S = \dfrac{WHLd}{\Delta I}$, in which S = fiber stress, W = load in pounds, H = height of fall in inches, L = length of span in inches, d = depth of beam in inches, Δ = deflection in inches, I = moment of inertia.

† $E = \dfrac{SL^2}{6\,\Delta d}$, in which E = modulus of elasticity, and other values as above.

‡ $R = \dfrac{3\,WHd^2}{4\,ALr^2}$, in which R = modulus of resilience, A =

men plot a curve, using the squares of the deflections as abscissas and the heights of fall as ordinates. The point at which the curve departs from a straight line indicates the elastic limit.*

area of cross section, r = radius of gyration, and other values are as heretofore defined. $\left(R = \frac{1}{2}\frac{S_e^2}{E}\right.$, in which S_e is the unit stress at the elastic limit.$\left.\right)$

* $\Delta^2 = \frac{WHL^3}{24EI}$, in which the values are the same as in the formulas given for S, E, and R.

CHAPTER VI.

TESTS OF WOOD.

PROBLEM D1.

Tensile Test of Wood.

251. **Object.** This experiment is for the purpose of determining the tensile strength of the kinds of wood tested.

252. **Apparatus Required.** A vertical-screw testing machine of 50,000 or 100,000 pounds capacity, with flat jaw grips, and a measuring scale or steel rule.

253. **Materials Required.** Three or more specimens of each kind of wood to be tested. A suitable form for the test pieces is shown in Fig. 54.

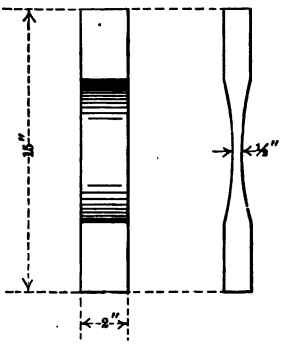

Fig. 54. — Specimen for Tensile Test of Wood

254. **Method of Operation.** Record the kind of wood and the dimensions for each specimen. Place one specimen in the grips of the machine, and apply the load using the second speed. As the load increases the wood between the two jaws of each head will be compressed, thus allowing them

to slide in the direction of pull. For this reason the small ends of the jaws should not be out flush with the surface of the head at the beginning of the test. Also, see that the specimen is thrust well back into each set of jaws. Use care to set the specimen plumb, in order that it may receive a direct pull, without any twisting in the grips. Record the maximum load and the method of failure. Test the remaining specimens in a similar manner.

255. **Report.** Tabulate the data and results, stating the kind of wood, dimensions of test piece, area of section, observed load and unit stress for each test piece. Also, state the average unit stress for each kind of wood and the probable error* for each average. Compare your results with the values of the ultimate tensile strength given in your textbooks, reporting the values found and the authority for each.

* For formula for probable error, see paragraph 129, p. 76.

PROBLEM D2.

Longitudinal Shear of Wood.

256. **Object.** This experiment is for the purpose of determining the shearing strength along the grain of the various kinds of wood tested.

257. **Apparatus Required.** A vertical-screw testing machine of 50,000 or 100,000 pounds capacity, with flat jaw grips for one head only, a shearing device similar to that shown in Fig. 55, a plate or collar with a 3-inch hole, a steel pin $\frac{7}{8}$ inch in diameter by 6 inches in length, and a measuring scale or steel rule.

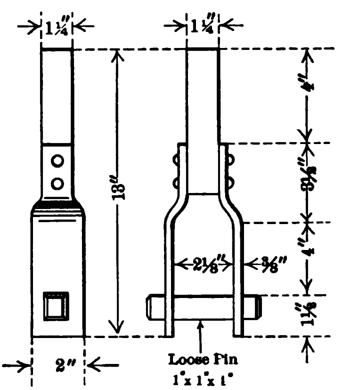

Fig. 55. — Device for Testing Longitudinal Shear of Wood

258. **Materials Required.** Three or more specimens of each species of wood to be tested. The form of the test piece is shown in Fig. 56.

259. **Method of Operation.** Observe and record the kind of wood and the dimensions of each test piece. Remove all attachments from the fixed head of the testing machine, and place the shearing

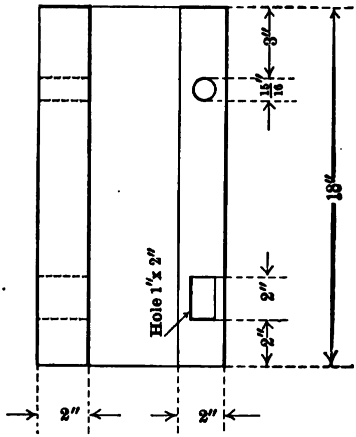

Fig. 56. — Form of Specimen for Longitudinal Shear Test of Wood

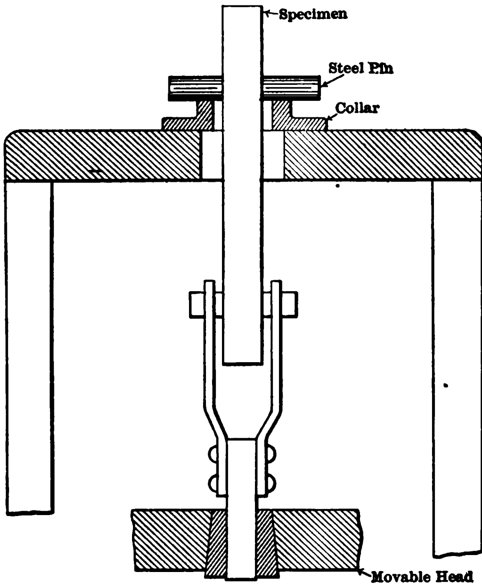

Fig. 57. — Arrangement for Testing Longitudinal Shear of Wood

device in the grips of the movable head. Place one test piece in position as shown in Fig. 57. Apply the load, keeping the scale beam balanced until failure occurs. A speed somewhat faster than the slowest will probably be desirable. Record the breaking load, character of failure, and any other observations of interest. Test each specimen in a similar manner.

260. **Report.** Tabulate the data and results, stating species of wood, dimensions, area of shearing section, total load, and unit shear for each specimen. Also, report the average unit shear for each kind of wood, and the probable error* for each average. Compare your results with the values for longitudinal shear given in your textbooks, reporting the values found and the authority.

* For formula for probable error, see paragraph 129, p. 76.

PROBLEM D3.

Crushing Strength of Wood.

261. **Object.** This experiment is for the purpose of determining the ultimate compressive strength of the species of wood tested, both along and across the grain.

262. **Apparatus Required.** A 100,000-pound testing machine, with compression block attached to the movable head, and a measuring scale or steel rule.

263. **Materials Required.** Six or more specimens of each kind of wood to be tested, each specimen to be 2 by 4 by 4 inches. One-half of the number of specimens of each kind should have true faces for compression across the grain, and the other half should have true faces for compression along the grain, the area of cross section in compression for each set being 2 by 4 inches.

264. **Method of Operation.** Observe and record the species of wood and the dimensions for each specimen. Place one specimen upon the table of the testing machine or upon an iron or steel block set upon the table of the machine.* Run the movable head down until the compression block is in contact with the specimen. Apply the load, using the slowest speed. Observe and record the maxi-

* The latter method is preferable since it does not require the movable head to be run down close to the table.

mum load, the character of failure, and any other observations of interest. Test each specimen in a similar manner, placing half of the number of specimens of each kind so that they will receive compression across the grain and the others so that they will receive compression along the grain.

265. **Report.** Tabulate the data and results, stating species of wood, dimensions, area of cross section, total load, and maximum unit stress for each specimen. Also, state the average unit stress for each set of results, and the probable error* of each average. Compare your results with the values for crushing strength of wood given in your textbooks, reporting the values found and the authority.

* For formula for probable error, see paragraph 129, p. 76.

PROBLEM D4.

Flexural Test of Wood.

266. Object. This experiment is for the purpose of determining the ultimate flexural strength, the modulus of elasticity, and the horizontal shearing strength * of the specimens tested.

267. Apparatus Required. A testing machine, preferably a small machine adapted to transverse tests of wood, similar to Fig. 30, page 37, or a vertical screw-testing machine with wings for testing beams and a V-block for applying the load. If the latter machine is used, there will also be required two rocker or roller supports, three steel plates for bearing against the wood, a mirror and scale, and some thread.

268. Materials Required. Three or more specimens of each kind of wood, the size of the specimens depending upon the capacity of the machine. For a 100,000-pound testing machine pieces 2 by 4 inches by 4 feet 6 inches in length or 4 by 4 inches by 6 feet 6 inches in length will be suitable.

269. Method of Operation. Measure and record the dimensions of each specimen and mark the position of the points of support and the point of application of the load. If a machine similar to

* The horizontal shearing strength is to be determined for only those specimens which fall by shearing along the neutral axis.

Fig. 30 is used, place one specimen in position and set the deflection indicator. Apply the load in increments of not more than one-tenth of the estimated ultimate load, observing and recording the deflection for each load. Record the maximum load and the method of failure. Test each specimen in a similar manner.

270. If a 100,000-pound testing machine is used, place the rocker or roller supports on the wings of the table of the machine, spacing them at equal distances on either side of the bearing block. For 2- by 4-inch lumber use a span of 4 feet, and for 4- by 4-inch lumber use a 6-foot span. Place 2- by 4-inch pieces so that the depth of the beam will be 2 inches. Place a steel plate between each support and the beam, and place one plate between the beam and the bearing block. At the center of one side of the beam attach the mirror and scale in a vertical position. Drive a nail into the side of the beam at the neutral surface and over each support. Stretch a thread from one nail, in front of the mirror and scale, to the other nail, allowing it to pass over the nail to a weight. Bring the eye on a level with the thread and its image in the mirror, and observe the reading on the scale. Apply the load in increments of not more than one-tenth of the estimated ultimate load, observing and recording the deflection reading for each increment. Record the maximum load and the method of failure. Test each specimen in a similar manner.

271. Report. Tabulate the data and results, stating the kind of wood, length of span, dimensions of cross section, the section factor, the total load for each reading, the unit flexural stress for each reading, the deflection readings, the deflections, the coefficient of elasticity for each deflection within the elastic limit, the unit horizontal shear for the maximum load, and the method of failure. For those specimens of each kind which fail by cross-breaking, compute the mean value of the modulus of rupture, and for those specimens which fail by longitudinal shear compute the mean value of the maximum unit horizontal shear. Also, compute the mean value of the coefficient of elasticity for each kind of wood. Plot a curve for each specimen using as abscissas the loads observed and as ordinates the deflections. Mark the point at which the elastic limit occurs, and determine the corresponding stress.

PROBLEM D5.

Impact Test of Wood.

272. **Object.** This experiment is for the purpose of determining the fiber stress at the elastic limit, the modulus of elasticity, and the modulus of resilience of the wood tested, when subjected to suddenly applied loads, and for the purpose of exhibiting the behavior and method of failure of the given materials under such loads.

273. **Apparatus Required.** The same equipment as for Problem C7.

274. **Materials Required.** A number of specimens of each kind of wood to be tested, in the form of beams 2 by 2 inches by 3 feet 6 inches, and paper for the recording drum.

275. **Method of Operation.** Follow the instructions for Problem C7.

276. **Report.** Follow the instructions for Problem C7.

CHAPTER VII.

TESTS OF BRICK.

PROBLEM E1.

Transverse Test of Brick.

277. **Object.** This experiment is for the purpose of determining the modulus of rupture of the brick tested.

278. **Apparatus Required.** A 50,000- or 100,000-pound testing machine with V-shaped bearing block, two rocker or roller supports, three steel plates $\frac{1}{4}$ by $1\frac{1}{2}$ by 5 inches, a wooden pillow block 5 by 5 by 12 inches, with one 5- by 12-inch surface slightly crowned from the center to each side, and a good rule (preferably graduated to inches and tenths of inches).

279. **Materials Required.** Five or more bricks of each kind.

280. **Method of Operation.*** Place the pillow block on the center of the table of the testing machine, with the crowned surface up. Place the

* The method here used is in accordance with the method recommended by Committee D of the American Society for Testing Materials, for which see Proceedings of that society, Vol. IX, page 131.

rockers or rollers upon the pillow block, making the span 7 inches, and having the center of span vertically under the V-shaped bearing block of the movable head. Measure and record the dimensions of all of the specimens. Place one brick flatwise upon the rockers or rollers, with a steel plate between each support and the brick. Place a similar plate on top of the brick and under the bearing block. Apply the load, using the slow motion, observing and recording the breaking load and the character of the failure. Save the half bricks resulting from the test for use in making compression and absorption tests. Test each brick in a similar manner.

281. Report. Tabulate the data and results stating the kind of brick, brand or name of manufacturer, dimensions, breaking load, modulus of rupture,* and method of failure for each specimen. Also, state the average value of the modulus of rupture for each set, and compute the probable error† of each average. Compare your results with the values given in your textbooks, reporting the values found and the authority.

* $M_r = \frac{3\,WL}{2bd^2}$, in which M_r = modulus of rupture, W = load in pounds, L = length of span in inches, b = breadth in inches, and d = depth in inches.

† For formula for probable error, see paragraph 129, p. 76.

PROBLEM E2.

Absorption Test of Brick.

282. **Object.** This experiment is for the purpose of determining the percentage of water absorbed by the brick tested.

283. **Apparatus Required.** Drying oven, thermometer, Harvard Trip balance with set of weights, and a sufficient number of deep-covered pans to accommodate all of the specimens.

284. **Materials Required.** One half of each brick tested in Problem E1, blotting paper, and water.

285. **Method of Operation.*** Weigh each specimen carefully, and mark it for future identification. Place the samples in a drying oven and dry them at a temperature of from 200° to 250° F. At intervals weigh each test piece, and permit the drying to continue until the weight remains constant. Then place the specimens in the covered pans, face downward, and pour in water to the depth of one inch. Cover the pans and allow them to stand. Weigh each specimen at intervals of one-half hour, six hours, and forty-eight hours from the time of immersion, first removing superfluous moisture. If the bricks are not to be used immediately for

* The method here used is in accordance with the method recommended by Committee D of the American Society for Testing Materials, for which see Proceedings of that society, Vol. IX, p. 132.

crushing tests, replace them in the water for future use. Compute the percentage of water absorbed to the weight of the dry specimen, in each case.

286. Report. Tabulate the data and results, stating the kind of brick, brand or name of manufacturer, original weight, weight dry, loss of weight, weight after immersion for each interval, increase in weight, and percentage of absorption, for each sample. Report the average percentage for each kind for each interval, and the probable error * of each average. Compare your results with values given in your textbooks, reporting the values found and the authority.

* For formula for probable error, see paragraph 129, page 76.

PROBLEM E3.

Compression Test of Brick.

287. **Object.** This experiment is for the purpose of determining the crushing strength of the brick tested.

288. **Apparatus Required.** A 100,000-pound testing machine with a spherical bearing block, and a rule.

289. **Materials Required.** All of the saturated specimens remaining from Problem E2, and the remaining halves of dry specimens from Problem E1, some blotting or building paper, and, if the specimens are rough, some shellac and plaster of Paris.

290. **Method of Operation.*** Measure and record the dimensions of each specimen. If the bricks are rough, coat the faces of the dry specimens with shellac. Place one specimen flatwise on the table of the testing machine or on an iron or steel pillow block, bedding the brick in building paper if reasonably smooth or in plaster of Paris if the surface is rough. Apply the load, using the slowest motion, observing and recording the maximum load. Test each specimen in a similar manner, keeping the results for wet and dry bricks separate.

* The method here used is in accordance with the method recommended by Committee D of the American Society for Testing Materials, for which see Proceedings of that society, Vol. IX, page 132.

291. Report. Tabulate the data and results, stating the kind of brick, brand or name of manufacturer, dimensions, area in compression, total load, and maximum unit stress. Report the average unit strength for dry brick and for wet brick, for each kind, and the probable error * of each average. Compare your results with the values given in your textbooks, reporting the values found and the authority.

* For formula for probable error, see paragraph 129, page 76.

PROBLEM E4.

Freezing and Thawing Test of Brick.

292. **Object.** This experiment is for the purpose of determining whether freezing and thawing will cause disintegration, cracking, spalling, or loss of strength of the brick tested.

293. **Apparatus Required.** Refrigerator cooled by freezing mixture or ammonia to maintain a temperature of less than 15° F., a drying oven, a boiler large enough to accommodate the specimens, a Harvard Trip balance and set of weights, and all of the equipment required for Problems E1 and E3.

294. **Materials Required.** Five or more bricks of each kind, water, ice, blotting or building paper, and possibly plaster of Paris.

295. **Method of Operation.*** Place the specimens in the boiler in cold water, and raise the temperature to 200° F. in thirty minutes, and then allow to cool Next immerse the specimens in ice water for not less than one hour, after which they are to be weighed and then transferred to the refrigerator. See that they are so placed in the refrigerator that all faces are exposed. Subject the

* The method here used is in accordance with the method recommended by Committee D of the American Society for Testing Materials, for which see Proceedings of that society, Vol. IX, page 132.

specimens to a temperature below 15° F. for at least five hours, then remove them and immerse them in water, the temperature of which is between 150° and 200° F., for one hour. Repeat the freezing and thawing twenty times, after which the bricks, still saturated, are to be weighed again. During the test observe and record any visible changes in the character of the specimens. Upon completion of the work above described, dry the specimens in an oven and test the flexural strength as explained in Problem E1. Subject the halves of bricks, resulting from the transverse test, to the crushing test, following the instructions for Problem E3.

296. Report. Tabulate the data and results, following the instructions given in Problems E1 and E3 for the results of the transverse and compression tests. In reporting the work for the first portion of the experiment, state weights called for, the temperatures in each case, the duration of time for each freezing or thawing, and the observations.

PROBLEM E5.

Rattler Test of Brick.

297. **Object.** This experiment is for the purpose of determining the resistance of the brick tested to impact and abrasion, as indicated by rattler test recommended by the National Brick Makers' Association.

298. **Apparatus Required.** A rattler similar to Fig. 36, page 44; 75 pounds of cast-iron shot, each weighing approximately $7\frac{1}{2}$ pounds, the dimensions being approximately $2\frac{1}{2}$ inches square by $4\frac{1}{2}$ inches long, with corners rounded to a radius of $\frac{1}{4}$ inch; 225 pounds of cast-iron shot, each of which weighs approximately $\frac{7}{8}$ pound, the form being a $1\frac{1}{2}$-inch cube with square corners and edges (old shot are to be replaced with new ones when they have lost one-tenth of their original weight); a good platform scale, a rule, and a drying oven.

299. **Materials Required.** Enough bricks or paving blocks of one kind so that their total volume will be as nearly as possible equal to 1000 cubic inches, or 8 per cent of the cubic contents of the rattler. (Nine, ten, or eleven will ordinarily be required.)

300. **Method of Operation.** See that the specimens are thoroughly dried before testing. Weigh each specimen and record the weight. Place the bricks and all of the cast-iron shot, called for under

"apparatus required," in the rattler, and close the cylinder. Start the rattler using a speed of not less than 28 nor more than 30 revolutions per minute, and continue the rotation through 1800 revolutions. Remove the specimens, weigh each, and record the weight. Compute the loss in terms of the weight of dry brick.

301. **Report.** Tabulate the data and results, stating the kind of brick, brand or name of manufacturer, dimensions, volume, original weight and final weight of each, average weight of specimens before testing, average weight after testing, loss of weight in pounds, percentage loss of weight, and any other observations of interest. Compare your results with specifications for paving brick, reporting the values found.

CHAPTER VIII.

TESTS OF SAND, GRAVEL, AND STONE.

PROBLEM F1.

Crushing Test of Stone.

302. **Object.** This experiment is for the purpose of determining the crushing strength of the stone tested.

303. **Apparatus Required.** A 100,000-pound testing machine with spherical bearing block, and a good rule.

304. **Materials Required.** Three or more specimens of each kind of stone, in the form of 1½-inch cubes, blotting or building paper, and possibly some plaster of Paris.

305. **Method of Operation.** Follow the instructions given in Problem B2, omitting the use of plaster of Paris, unless instructed otherwise.

306. **Report.** Follow the instructions for Problem B2.

PROBLEM F2.

Abrasion Test of Broken Stone.

307. **Object.** This experiment is for the purpose of determining the resistance to abrasion of stone intended for use in road construction.

308. **Apparatus Required.** A good weighing scale, a coarse balance, a drying oven, an abrasion cylinder similar to Fig. 37, page 45, and a $\frac{1}{16}$-inch mesh sieve.

309. **Materials Required.** At least 30 pounds of coarsely broken stone.

310. **Method of Operation.*** Wash the sample of stone and dry it in a drying oven. From the dried stone select, as nearly as possible, 50 pieces such that the total weight shall be within 10 grams of 5 kilograms. Record the exact weight. Place the sample in the abrasion cylinder, and set it in rotation at the rate of from 30 to 33 revolutions per minute. Continue the rotation through 10,000 revolutions. Remove the material from the cylinder, and screen it through a $\frac{1}{16}$-inch mesh sieve. Weigh the amount passing and the amount retained, and compute the percentage of material passing to the total weight. Also, compute the French coefficient which is $\frac{400}{W}$, in which W is the

* See Proceedings of American Society for Testing Materials, Vol. VIII, page 197.

weight in grams of detritus under $\frac{1}{16}$-inch in size per kilogram of stone used.

311. **Report.** Tabulate the data and results reporting all weights, losses, the percentage of loss, and the French coefficient. Compare your results with results of other tests, if such are available, reporting the values found.

PROBLEM F3.

*Toughness Test of Broken Stone.**

312. **Object.** This experiment is for the purpose of testing the toughness of broken stone, intended for use in road construction.

313. **Apparatus Required.** An impact testing machine, similar to Fig. 34, page 41.

314. **Materials Required.** Three or more specimens of each kind of stone, the form of test piece being either a cylinder or cubes, 25 millimeters in diameter by 25 millimeters in height, cut perpendicular to the stratification of the rock.

315. **Method of Operation.** Place one specimen in the machine under the plunger upon which the hammer falls. Start the machine, allowing the hammer to fall 1 centimeter for the first blow, 2 centimeters for the second blow, 3 centimeters for the third blow, and so on until failure occurs. Record the number of blows, and compute the energy of the last blow in centimeter-grams. Test each specimen in a similar manner.

316. **Report.** Tabulate the data and results, stating the kind of stone, form and size of specimen, number of blows and energy for each specimen, and the average number of blows and average amount of energy for each kind of stone.

* See Proceedings of American Society for Testing Materials, Vol. VIII, page 199.

PROBLEM F4.

Specific Gravity of Sand, Gravel, and Broken Stone.

317. **Object.** This experiment is for the purpose of exhibiting some of the methods which may be used for determining the specific gravity of such materials as sand, gravel, and stone.

318. **Apparatus Required.** Le Chatelier flask, glass rod, pipette, liter or 500-cubic centimeter graduated cylinder, Harvard Trip balance, triple-beam balance,* ordinary pail,† pans, and a good platform balance.

319. **Materials Required.** Samples of sand, gravel, and broken stone, and some water.

320. **Method of Operation.** Fill the specific gravity flask to the mark below the bulb with water, and after the water from the sides of the tube has run down, bring the surface exactly to the mark by means of the pipette. On the triple-beam balance weigh out 55 grams of one kind of sand. Pour the sand slowly into the specific gravity flask, using the glass rod to prevent clogging. Read the volume displaced. The specific gravity will be equal to the weight in grams divided by the volume

* See Fig. 10, p. 15.

† A deep can is better than a pail, since there will be a smaller proportionate error in the result for a given error in observation of height of surface.

in cubic centimeters displaced. To clean the flask agitate and rotate the flask to bring the sand into suspension, then turn the flask upside down, and allow the contents to run out.

321. Fill the graduated cylinder about half full of gravel. Pour the gravel into a pan and determine its weight carefully by the Harvard balance. Fill the graduated cylinder half full of water, noting the exact volume. Pour the gravel into the water in the cylinder and observe the total volume. The difference in the readings is the volume displaced. Compute the specific gravity in the same manner as for sand.

322. Place the empty pail upon the platform scale and weigh it. Fill the pail about three-fourths full of broken stone and observe the weight. Then pour the stone out of the pail, fill the pail level full with water and observe the weight. Pour out some of the water, place the weighed stone in the pail, fill the pail level full with water and observe the total weight. From the observed weights deduct the weight of pail to obtain the weight of water with the pail filled, weight of stone used, and weight of stone and water mixed. Subtract the weight of stone from the weight of the mixture to obtain the weight of water in the mixture. Then the difference between the weight of water for the pail filled and the weight of water in the mixture is the weight of water displaced, that is the weight of a volume of water equal to the actual volume of stone. The

specific gravity of the stone is the ratio of the weight of the stone to the weight of an equal volume of water. This method could have been used for sand or gravel, and it has the advantage that it can often be used where laboratory equipment is not available.

323. **Report.** Tabulate the data and results, stating all observations of volume and weight, and all computed results. Compare your results with values given in your textbooks, reporting the values found.

PROBLEM F5.

Percentage of Voids in Sand, Gravel, and Broken Stone.

324. **Object.** This experiment is for the purpose of showing some of the methods which may be used in determining the percentage of voids in sand, gravel, and broken stone.

325. **Apparatus Required.** Liter graduated cylinder, an ordinary pail, pans, and a good platform scale.

326. **Materials Required.** Samples of sand, gravel, and broken stone, and some water.

327. **Method of Operation.** Fill the graduated cylinder half full of one kind of sand or gravel, and observe the volume, first as poured in, and then after shaking to settle the mass. Pour the sand out into a pan, and fill the cylinder half full of water, observing the exact volume. Pour the measured sand into the water and observe the total volume. The difference between the two readings of the water level is the volume displaced. The volume observed for the dry sand minus the volume displaced is the volume of the voids. The ratio of the volume of voids to the volume of dry sand is the percentage of voids. Compute the percentage of voids both for the sand loose and for it settled. Test all of the samples of sand and gravel in a similar manner.

328. Place the empty pail upon the platform scale and observe its weight. Fill the pail with stone and observe the total weight. Empty the pail, fill it with water, and observe the weight. The weight of water in pounds divided by 62.5 is the volume of contents in cubic feet. The weight of the stone divided by 62.5 times the specific gravity * is the volume of solids in cubic feet. The volume of the pail minus the volume of the solids of the stone is the volume of voids. To obtain the percentage of voids divide the volume of the voids by the volume of the pail. This method may be used for sand or gravel as well as for stone.

329. Report. Tabulate the data and results, stating all observations of volumes and weights, and all computed results.

* If the specific gravity is unknown it may be determined as explained in paragraph 322, p. 150. For ordinary purposes the following values of specific gravity may be used: sand or gravel, 2.65; limestone, 2.53; sandstone, 2.22; granite, 2.67; marble, 2.72; and slate, 2.78. These values are taken from Baker's Masonry, pages 6 and 91, 1909 edition.

PROBLEM F6.

Sieve Analysis of Sand, Gravel, and Broken Stone.

330. **Object.** This experiment is for the purpose of investigating the absolute and relative sizes of particles of the materials tested.

331. **Apparatus Required.** Sieves of the following mesh: No. 100, No. 70 or No. 80, No. 50, No. 30, No. 20, No. 10, $\frac{1}{4}$-inch, $\frac{1}{2}$-inch, $\frac{3}{4}$-inch, 1-inch, $1\frac{1}{2}$-inch, and 2-inch; fine balance, triple-beam balance, and Harvard balance.

332. **Materials Required.** Samples of sand, gravel, and broken stone, logarithmic coördinate paper, and ordinary coördinate paper.

333. **Method of Operation.** On the triple-beam balance weigh out 100 grams of sand, screen it through the $\frac{1}{4}$-inch sieve, and weigh the amount retained and the amount passing. Place the amount passing on the No. 10 sieve and repeat the operation. Continue in this manner to screen the sample through the remainder of the finer-meshed sieves. From the last grains passing each sieve count out 100 particles, and weigh each hundred on the fine balance. Compute the average diameter* of each size, assuming the particles to be spheres.

* $d = \sqrt{\frac{6\,W}{100\,\pi\,(\text{S.G.})}}$, in which d = diameter in cm., W = weight in grams of 100 grains of sand, S.G. = specific gravity of material, which may be determined as explained in Problem F4, if not already known.

334. Screen and weigh the gravel as directed for sand, but begin with as coarse a sieve as will retain any of the pebbles and use 1000 instead of 100 grams. Weigh the material on the Harvard balance, instead of the triple-beam balance. The determination of diameter of particles by the method explained for sand will not be required unless special instructions are given to that effect.

335. Screen and weigh the broken stone as directed for gravel.

336. **Report.** Plot the results for the analysis of the sand upon logarithmic coördinate paper, using diameter of grains in millimeters as abscissas and percentage by weight as ordinates. Connect the points with a curve. Observe the points at which the curve intersects the 10 per cent line and the 60 per cent line. The diameter of grains corresponding to the first point is the effective size, and the ratio of the diameter for second point to the effective size is the uniformity coefficient. Tabulate the data and results obtained, and hand in upon a separate sheet all of your numerical computations, being careful to arrange your work so that it can be easily understood. For the sand, the gravel, and the stone plot curves upon ordinary coördinate paper, using as abscissas diameter of particles in inches, and for ordinates percentages by weight. In this case the diameter of particles may be taken directly from the sizes of openings of the sieves.

PROBLEM F7.

Proportions for Concrete Aggregates.

337. **Object.** This experiment is for the purpose of determining the proper proportion for given samples of sand, gravel, and broken stone to be used as the aggregate for concrete.

338. **Apparatus Required.** A pail or large can, pans, and a good platform scale.

339. **Materials Required.** A supply of sand, gravel, and broken stone, for each of which the percentage of voids * has been determined, and for each of which a sieve analysis † has been made.

340. **Method of Operation.** Mix together equal parts by weight of gravel ‡ and stone, also, one part of gravel to two parts of stone, and one part of gravel to three parts of stone. Make a fourth mixture of sand, gravel, and stone, the proportions being determined by investigation of the sieve-analysis curves.§ Upon the coördinate paper on which the sieve-analysis curve for each of the materials to be used is plotted, draw a parabola,||

* See Problem F5. † See Problem F6.

‡ If the gravel is very coarse use a mixture of one part of sand to two parts of gravel for the first three mixtures.

§ The method used is that devised by Wm. B. Fuller, a description of which is given in Taylor and Thompson's "Concrete Plain and Reinforced" (1905 edition), pp. 183–215.

|| If so instructed use the elliptical curve, as explained in Transactions of the American Society of Civil Engineers, Vol. LIX, p. 90, in place of the parabolic curve.

beginning at the zero of the ordinates and passing through the point at the intersection of the line for the largest size of stone with the 100 per cent line. Find the point on the parabolic curve vertically above the point at which the stone curve crosses the zero per cent line, and observe the percentage value corresponding to the intersection.* The amount observed subtracted from 100 will give the percentage of the final mixture, which should be stone. For the portions of the curves for sand and gravel, the horizontal projections of which overlap, observe which curve has the larger vertical projection. If the sand curve has the larger vertical projection, use the upper end of the sand curve as a starting point, otherwise use the lower end of the gravel curve, or take the mean of the results by both methods. From the starting point follow the vertical to its intersection with the parabolic curve, and also to its intersection with remaining curve. Compute the ratio of the distance along the vertical between the gravel curve and the parabola to the distance between the gravel curve and the sand curve. The ratio found will be the percentage of the total mixture which should be sand. The remaining percentage of the total mixture should be gravel. Mix together a sample of aggregate,

* If the gravel and stone curves overlap to any considerable extent, the overlapping portions can be treated in a manner similar to that explained in this problem for the sand and gravel curves.

using the proportions determined by the curves. Compute the curve which should be obtained for the mixture, and check your results by screening a portion of the mixed sample as explained in Problem F6. For each of the four mixtures of aggregate, determine the percentage of voids as explained in paragraph 328, page 153.

341. **Report.** Tabulate the data and results, stating all quantities observed. Hand in the curves and all of your computations.

CHAPTER IX.

TESTS OF ASPHALT.

PROBLEM G1.

Purity of Asphalt.

342. **Object.** The object of this test is to determine the percentage of material in the samples submitted which will not be dissolved by various solvents.

343. **Apparatus Required.** Fine balance, Gooch crucible with long-fiber amphibole asbestos filters, stand for supporting crucible, evaporating dish, and flasks.

344. **Materials Required.** Small samples of pure* bitumen, free from water, carbon disulphide, carbon tetrachloride, and naphtha.

345. **Method of Operation.** On the fine balance weigh out two samples of 1 gram each, and one sample of ½ gram, of the material to be tested. Place a 1-gram sample in a flask with 100 cubic centimeters of carbon disulphide, another 1-gram sample in a flask with 200 cubic centimeters of carbon tetrachloride, and the ½-gram sample, finely divided, in a flask with 150 cubic centimeters of

* Not mixed with sand.

naphtha. Record the specific gravity of the naphtha. Cork the flasks loosely, shake them from time to time, and then set them away until the next laboratory period. (The interval should be at least 15 hours.) At that time filter the contents of each flask using the Gooch crucible and filter, having first weighed the crucible. Allow the residue of each to stand until dry, warming it to assist in evaporating any remaining solvent. Return the used solvents to vessels kept for that purpose, in order that they may be distilled for future use. Weigh the crucible and residue and compute the weight of residue, for each solvent. Place 1 gram of divided bitumen on a weighed Gooch crucible and filter, and wash with carbon disulphide until the washings are clear. Dry the filter, weigh it, and compute the residue as before.

346. **Report.** Tabulate the data and results, stating all weights, computations, and observations. Compare your results with specifications, if any are at hand, and report the requirements found.

PROBLEM G2.

Percentage of Bitumen in Paving Mixtures.

347. **Object.** This experiment is for the purpose of determining the amount of bitumen present in the given samples of asphaltic paving mixtures.

348. **Apparatus Required.** Fine balance, Gooch crucible with long-fiber amphibole asbestos filters, stand for supporting crucible, evaporating dish, and flasks.

349. **Materials Required.** Samples of dry asphaltic paving mixtures, and carbon disulphide.

350. **Method of Operation.*** Observe and record the weight of a 150-cubic-centimeter Erlenmeyer flask. Weigh out from 1 to 10 grams of a sample to be tested, crush it and place it in the flask with 100 cubic centimeters of carbon disulphide. Loosely cork the flask, shake it from time to time until practically all of the particles have been broken up, using glass beads in the flask, if desired, to assist in breaking up the lumps. The flask is then set aside for not less than 15 hours (or until the next laboratory period, unless otherwise instructed). At the end of this time the contents of the flask are to be decanted off upon a

* The method here used is the Rapid Method for the Determination of Material in Bituminous Road Compounds Soluble in Cold Carbon Disulphide as recommended by Committee H of the American Society for Testing Materials, given in Proceedings of the American Society for Testing Materials, Vol. IX, page 222.

weighed Gooch crucible with a long-fiber amphibole asbestos filter. The residue in the flask is then to be washed with 50 cubic centimeters of carbon disulphide, allowed to settle, and decanted as before. The insoluble matter in the flask is then to be placed upon the filter and washed with carbon disulphide until the washings are practically colorless. Then dry the filter and contents at 125° C., and cool and weigh it. Should any residue remain in the flask, it is to be dried and weighed, and the weight of residue added to the weight of residue in the crucible. Also, burn off the filtrate in an evaporating dish, and with a Bunsen burner ignite the residue to an ash and weigh the ash. Add the weight of ash to the weight of insoluble residue. The weight of the total residue deducted from that of the original material gives the weight of bitumen soluble in cold carbon disulphide. In this case the percentage of insoluble residue, determined as above, minus that of any ash which may be found by igniting a separate sample, is reported as free carbon. This test shall be carried on at a temperature of from 20° to 25° C.

351. **Report.** Tabulate the data and results, stating all weights, computations, and observations. Compare your results with the specifications under which the asphaltic mixtures were prepared, if such are available.

PROBLEM G3.

*Penetration Test of Asphalt.**

352. **Object.** This experiment is for the purpose of determining the consistency of the samples tested, as indicated by the penetration of a needle.

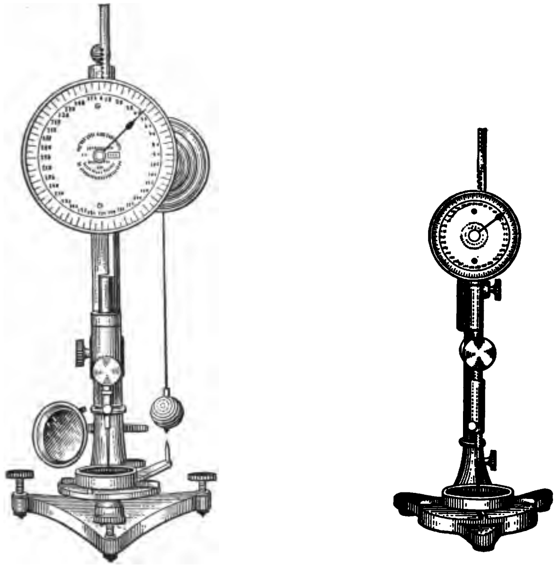

Fig. 58. — Penetrometers for Testing Asphalt

353. **Apparatus Required.** Penetrometer, similar to one of those shown in Fig. 58, having a No. 2

* The method here used is in accordance with the Method for the Determination of the Consistency of Bitumen, recommended by Committee H of the American Society for Testing Materials, for which see Vol. IX, page 223, of Proceedings of that society.

needle under a weight of 100 grams, basin or receptacle for use in immersing specimen in water, and thermometer.

354. **Materials Required.** Samples of pure asphalt in tin boxes ½ inch to 1 inch deep by 2⅜ inches diameter, some water and possibly some ice.

355. **Method of Operation.** Fill the basin with water, note its temperature, and if necessary add hot water or ice water to bring its temperature to 25° C. (77° F.). Place one of the samples in position under the needle of the penetrometer, with the sample immersed in water. See that the water is at the temperature stated, and allow the sample to remain immersed long enough to come to the temperature of the water, before testing the penetration.* Then bring the point of the needle and the surface of the sample in contact and determine the penetration in 5 seconds of time. Record the number of degrees on the scale. Test each sample in a similar manner.

356. **Report.** Tabulate the data and results, stating all observations. Compare your results with specifications for asphalt, if such are available, and report the comparison.

* If possible place the samples in the water some time before going ahead with the test, in order that they may be at the proper temperature at the time desired.

PROBLEM G4.

*Residual Coke in Asphalt.**

357. **Object.** This experiment is for the purpose of determining the amount of fixed carbon in the given samples of asphalt.

358. **Apparatus Required.** Fine balance, platinum triangle and support, and platinum crucible weighing 20 to 30 grams and having a tight-fitting cover.

359. **Materials Required.** Samples of pure asphalt.

360. **Method of Operation.** Place 1 gram of one sample, free from water, in the platinum crucible and see that the cover is tight. Place the crucible on the platinum triangle, with the bottom 6 to 8 centimeters above the top of the burner. See that the flame is fully 20 centimeters high when burning free, and that the flame is free from draughts. The upper surface of the cover should burn clear, but the under surface should remain covered with carbon. Continue the heating for 7 minutes. Weigh the crucible to determine the residue. The residue minus the small impurity of ash in the pure bitumen is the fixed carbon, which should be calculated to

* The method here used is in accordance with Method for the Determination of Residual Coke in Bituminous Compounds, recommended by Committee H of the American Society for Testing Materials, for which see Vol. IX, page 223, of Proceedings of that society.

100 per cent with the volatile hydrocarbons, excluding the inorganic matter. Test each sample in a similar manner.

361. **Report.** Tabulate the data and results, stating all weights, observations, and computations.

PROBLEM G5.

*Loss on Heating.**

362. **Object.** This experiment is for the purpose of determining the amount of volatile matter in the given samples, which can be expelled by heating.

363. **Apparatus Required.** Hot-air oven, fine balance, and all of the equipment required for Problem G3.

364. **Materials Required.** Samples of pure water-free asphalt in tin boxes 1 inch deep by $2\frac{3}{8}$ inches diameter, containing 50 grams each, and water.

365. **Method of Operation.** Determine the penetration for each sample, as directed in Problem G3. Then weigh each sample on the balance, and place it in the hot-air oven. Raise the temperature to 170° C., and maintain this temperature for 5 hours. At no time shall the temperature of the oven vary more than 2° C. from 170° C. When the sample is cooled to normal temperature, it is to be weighed, and the percentage of loss computed. Then make another determination of the penetra-

* The method here given is in accordance with Method for the Determination of the Loss on Heating of Oil and Asphaltic Compounds recommended by Committee H of the American Society for Testing Materials, for which see Vol. IX, page 223, of Proceedings of that society.

tion for each sample, as directed in Problem G3. Compute the loss in penetration.

366. **Report.** Tabulate the data and results, stating all weights, computations, observations, the loss by volatilization, and the loss in penetration.

PROBLEM G6.

Ductility of Asphalt.

367. **Object.** This experiment is for the purpose of determining the ductility of the given samples of asphalt.

368. **Apparatus Required.** Flasks, a still, 20-mesh sieve, 50-mesh sieve, amalgamated brass plates, briquette molds similar to Fig. 59, a ductility machine, steam bath, and the apparatus required for Problems G1 and G3. A ductility machine is shown in Fig. 60, for which the pull is horizontal. For very ductile materials a better form of machine is one in which the pull is vertical.*

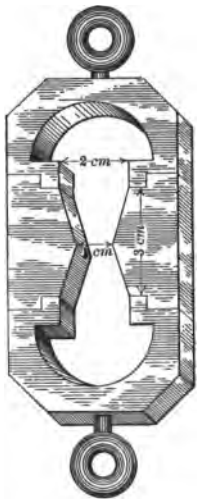

Fig. 59. — Briquette Mold for Asphalt

369. **Materials Required.** Samples of asphaltic cement, carbon disulphide, and refined liquid asphalt free from water and from light oils volatile at less than 250° F.

370. **Method of Operation.**† Test the purity of each sample

* For a description and illustration of such a machine, see "A Machine for Testing the Ductility of Bituminous Cements," by Francis P. Smith, in Proceedings of the American Society for Testing Materials, Vol. IX, page 594.

† The method here used is that given by Francis P. Smith, in the article noted in the preceding footnote.

to determine the percentage of material soluble in carbon disulphide, as explained in Problem G1. Classify the samples as follows: Class 1, asphalts containing over 96 per cent soluble matter and free from lumps of inert bitumen; Class 2, asphalts containing less than 96 per cent soluble matter

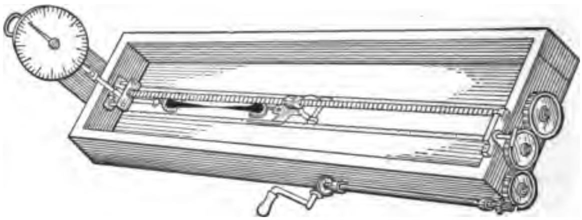

Fig. 60. — Ductility Machine

and free from lumps of inert bitumen; Class 3, asphalts which are not homogeneous, *i.e.*, containing lumps of hard bitumen which, although soluble in carbon disulphide, are insoluble in the softer bitumen, even in a molten condition. Asphalts coming under the first classification need no preliminary treatment.

371. To prepare asphalts of Class 2 for use, proceed as follows: take a sufficient quantity of one material to yield 150 grams, after treatment. Treat the sample with carbon disulphide in an Erlenmeyer flask for 2 or 3 hours, shaking the flask occasionally until none of the asphalt adheres to the sides or bottom, after which it is to be set aside for 24 hours. Then decant the solvent from

the flask, into a second flask, and again treat the residue with more carbon disulphide, shaking, allowing to subside, and decanting as before. Continue until the solvent is practically colorless. Allow the combined solutions to stand for at least 24 hours after the last addition, and then decant off the solvent into the still, and distill until only sufficient solvent remains to keep the extracted bitumen liquid. Pour the residue into a large evaporating dish and place upon the steam bath, to evaporate as much as possible of the remaining solvent. To facilitate the removal of the last particles of carbon disulphide from the bitumen, while on the steam bath, it should be stirred from time to time. After this treatment, incorporate $\frac{1}{2}$ to 1 cubic centimeter of water into the bitumen and, while stirring the material continually with a thermometer, heat the sample over a burner until all foaming ceases. Next place the sample in a hot-air oven and maintain it at a temperature of 300° F. for 30 minutes. (See that the temperature never exceeds 300° F.)

372. To prepare asphalt of Class 3, for use, proceed as follows: Heat the sample in an air bath at a temperature between 300° and 350° F., together with a 20-mesh sieve and a 50-mesh sieve. When the material is in a thoroughly molten condition, it is to be first strained through the heated 20-mesh sieve, and then through the 50-mesh sieve, allowing it to run by gravity. If the material thus

obtained contains less than 96 per cent of bitumen soluble in carbon disulphide, it must be treated as materials under Class 2, otherwise it is ready for use.

373. Determine the penetration for each sample, as explained in Problem G3, using a Dow penetrometer. If the material is not of proper consistency, *i.e.*, 50 penetration at 77° F., it is to be softened with the liquid asphalt.* With the material as thus prepared mold three or more briquettes with each asphalt to be tested. Before molding, examine the molds and the brass plate to see that the surface of the plate and the inner surfaces of the removable pieces of the molds are well amalgamated, to prevent adhesion. Place the molds on the plate and fasten the parts of each mold together with a clamp or rubber band. Melt each sample of asphalt, and with it fill three or more molds, while the material is in a molten state. Add a slight excess to each briquette to allow for shrinkage on cooling. After the briquettes are cool, smooth each off level by means of a heated palette knife.

374. When ready to test the briquettes, remove the two side pieces of one briquette, leaving the asphalt firmly attached to the two ends of the mold, which serve as clips. Immerse each briquette in water, the temperature of which is to be

* In practice the flux used should be the same as will be used in the work.

maintained at 77° F. for at least 30 minutes, or until the whole mass of bitumen is at that temperature. Examine the ductility machine to determine the rate of motion of the hand wheel which will cause the ends of the briquette to be pulled apart at the rate of 5 centimeters per minute. Then place one briquette in position in the machine, set the pointer to read zero, and pull the briquette apart at the determined speed. Note the reading of the pointer at the instant that thread of bitumen breaks, to obtain the ductility of the sample expressed in centimeters. Test each briquette in a similar manner.

375. **Report.** Tabulate the data and results, stating all operations, observations, and computations. Compare your results with any data of other tests which may be available, and report the comparison.

APPENDICES

APPENDIX I.

PROGRESS REPORT OF COMMITTEE ON UNIFORM TESTS OF CEMENT OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS.*

PRESENTED AT THE ANNUAL MEETING JANUARY 20, 1909.

SAMPLING.

1. SELECTION OF SAMPLE. The selection of the sample for testing is a detail that must be left to the discretion of the engineer; the number and the quantity to be taken from each package will depend largely on the importance of the work, the number of tests to be made, and the facilities for making them.

2. The sample shall be a fair average of the contents of the package; it is recommended that, where conditions permit, one barrel in every ten be sampled.

3. Samples should be passed through a sieve having twenty meshes per linear inch, in order to break up lumps and remove foreign material; this is also a very effective method for mixing them together in order to obtain an average. For determining the characteristics of a shipment of cement, the individual samples may be mixed and the average tested; where time will permit, however, it is recommended that they be tested separately.

4. METHOD OF SAMPLING. Cement in barrels should be sampled through a hole made in the center of one of the staves, midway between the heads, or in the head, by means

* Authorized Reprint from Proceedings of the American Society of Civil Engineers, Vol. 35, No. 2, Feb., 1909.

of an auger or a sampling iron similar to that used by sugar inspectors. If in bags, it should be taken from surface to center.

Chemical Analysis.

5. Significance. Chemical analysis may render valuable service in the detection of adulteration of cement with considerable amounts of inert material, such as slag or ground limestone. It is of use, also, in determining whether certain constituents, believed to be harmful when in excess of a certain percentage, as magnesia and sulphuric anhydride, are present in inadmissible proportions.

6. The determination of the principal constituents of cement — silica, alumina, iron oxide, and lime — is not conclusive as an indication of quality. Faulty character of cement results more frequently from imperfect preparation of the raw material or defective burning than from incorrect proportions of the constituents. Cement made from very finely-ground material, and thoroughly burned, may contain much more lime than the amount usually present and still be perfectly sound. On the other hand, cements low in lime may, on account of careless preparation of the raw material, be of dangerous character. Further, the ash of the fuel used in burning may so greatly modify the composition of the product as largely to destroy the significance of the results of analysis.

7. Method. As a method to be followed for the analysis of cement, that proposed by the Committee on Uniformity in the Analysis of Materials for the Portland Cement Industry, of the New York Section of the Society for Chemical Industry, and published in *Engineering News*, Vol. 50, page 60, 1903, and the *Engineering Record*, Vol. 48, page 49, 1903, is recommended.

Specific Gravity.

8. Significance. The specific gravity of cement is lowered by underburning, adulteration, and hydration, but the adulteration must be in considerable quantity to affect the results appreciably.

9. Inasmuch as the differences in specific gravity are usually very small, great care must be exercised in making the determination.

10. Apparatus and Method. The determination of specific gravity is most conveniently made with Le Chatelier's

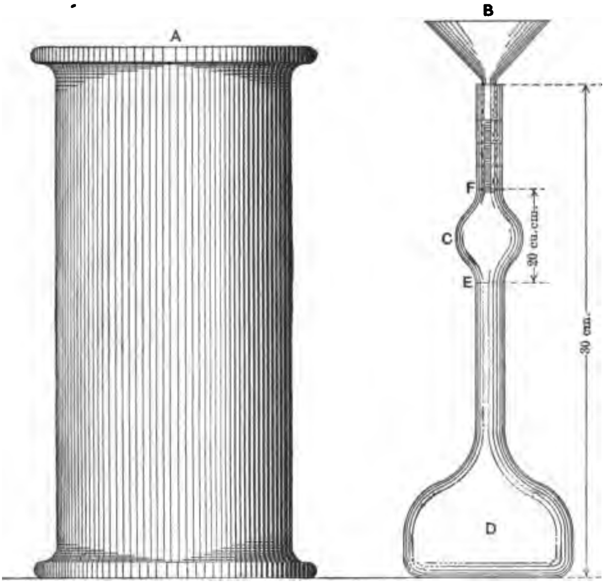

Fig. 61. — Le Chatelier's Specific Gravity Apparatus

apparatus. This consists of a flask (*D*), Fig. 61, of 120 cu. cm. (7.32 cu. ins.) capacity, the neck of which is about 20 cm. (7.87 ins.) long; in the middle of this neck is a bulb (*C*),

above and below which are two marks (*F*) and (*E*); the volume between these marks is 20 cu. cm. (1.22 cu. ins.). The neck has a diameter of about 9 mm. (0.35 in.), and is graduated into tenths of cubic centimeters above the mark (*F*).

11. Benzine (62 degrees Bäumé naphtha), or kerosene free from water, should be used in making the determination.

12. The specific gravity can be determined in two ways: (1) The flask is filled with either of these liquids to the lower mark (*E*), and 64 gr. (2.25 oz.) of powder, cooled to the temperature of the liquid, is gradually introduced through the funnel (*B*) [the stem of which extends into the flask to the top of the bulb (*C*)], until the upper mark (*F*) is reached. The difference in weight between the cement remaining and the original quantity (64 gr.) is the weight which has displaced 20 cu. cm.

13. (2) The whole quantity of the powder is introduced, and the level of the liquid rises to some division of the graduated neck. This reading plus 20 cu. cm. is the volume displaced by 64 gr. of the powder.

14. The specific gravity is then obtained from the formula:

$$\text{Specific Gravity} = \frac{\text{Weight of Cement, in grams}}{\text{Displaced Volume, in cubic centimeters}}.$$

15. The flask, during the operation, is kept immersed in water in a jar (*A*), in order to avoid variations in the temperature of the liquid. The results should agree within 0.01. The determination of specific gravity should be made on the cement as received; and should it fall below 3.10, a second determination should be made on the sample ignited at a low red heat.

16. A convenient method for cleaning the apparatus is as follows: The flask is inverted over a large vessel, preferably a glass jar, and shaken vertically until the liquid starts to flow freely; it is then held still in a vertical position until

empty; the remaining traces of cement can be removed in a similar manner by pouring into the flask a small quantity of clean liquid and repeating the operation.

17. More accurate determinations may be made with the picnometer.

Fineness.

18. Significance. It is generally accepted that the coarser particles in cement are practically inert, and it is only the extremely fine powder that possesses adhesive or cementing qualities. The more finely cement is pulverized, all other conditions being the same, the more sand it will carry and produce a mortar of a given strength.

19. The degree of final pulverization which the cement receives at the place of manufacture is ascertained by measuring the residue retained on certain sieves. Those known as the No. 100 and No. 200 sieves are recommended for this purpose.

20. Apparatus. The sieves should be circular, about 20 cm. (7.87 ins.) in diameter, 6 cm. (2.36 ins.) high, and provided with a pan 5 cm. (1.97 ins.) deep, and a cover.

21. The wire cloth should be of brass wire having the following diameters:

No. 100, 0.0045 in.; No. 200, 0.0024 in.

22. This cloth should be mounted on the frames without distortion; the mesh should be regular in spacing and be within the following limits:

No. 100, 96 to 100 meshes to the linear inch.
No. 200, 188 to 200 meshes to the linear inch.

23. Fifty grams (1.76 oz.) or 100 gr. (3.52 oz.) should be used for the test, and dried at a temperature of 100° Cent. (212° Fahr.) prior to sieving.

24. Method. The Committee, after careful investigation, has reached the conclusion that mechanical sieving is

not as practicable or efficient as handwork, and, therefore, recommends the following method:

25. The thoroughly-dried and coarsely-screened sample is weighed and placed on the No. 200 sieve, which, with pan and cover attached, is held in one hand in a slightly inclined position, and moved forward and backward, at the same time striking the side gently with the palm of the other hand, at the rate of about 200 strokes per minute. The operation is continued until not more than one-tenth of 1 per cent passes through after one minute of continuous sieving. The residue is weighed, then placed on the No. 100 sieve and the operation repeated. The work may be expedited by placing in the sieve a small quantity of large steel shot. The results should be reported to the nearest tenth of 1 per cent.

Normal Consistency.

26. Significance. The use of a proper percentage of water in making the pastes* from which pats, tests of setting, and briquettes are made, is exceedingly important, and affects vitally the results obtained.

27. The determination consists in measuring the amount of water required to reduce the cement to a given state of plasticity, or to what is usually designated the normal consistency.

28. Various methods have been proposed for making this determination, none of which has been found entirely satisfactory. The Committee recommends the following:

29. Method. Vicat Needle Apparatus. This consists of a frame (*K*), Fig. 62, bearing a movable rod (*L*), with the cap (*A*) at one end, and at the other the cylinder (*B*), 1 cm. (0.39 in.) in diameter, the cap, rod, and cylinder

* The term "paste" is used in this report to designate a mixture of cement and water, and the word "mortar" a mixture of cement, sand, and water.

weighing 300 gr. (10.58 oz.). The rod, which can be held in any desired position by a screw (*F*), carries an indicator, which moves over a scale (graduated to centimeters) attached to the frame (*K*). The paste is held by a conical,

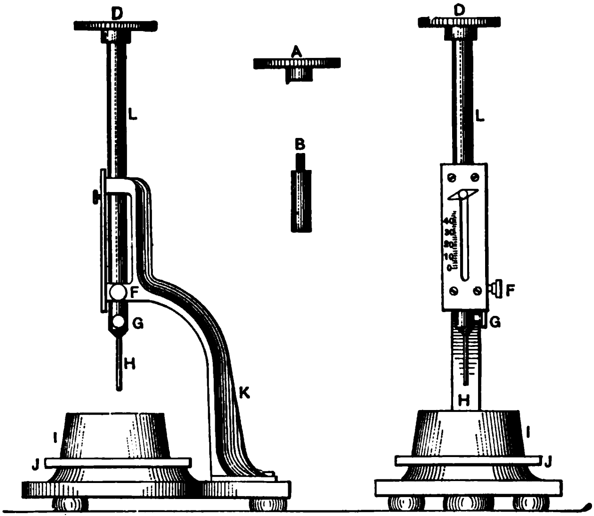

Fig. 62. — Vicat Needle

hard-rubber ring (*I*), 7 cm. (2.76 ins.) in diameter at the base, 4 cm. (1.57 ins.) high, resting on a glass plate (*J*), about 10 cm. (3.94 ins.) square.

30. In making the determination, the same quantity of cement as will be subsequently used for each batch in making the briquettes (but not less than 500 grams) is kneaded into a paste, as described in paragraph 58, and quickly formed into a ball with the hands, completing the operation by tossing it six times from one hand to the other, maintained 6 ins. apart; the ball is then pressed into the rubber ring, through the larger opening, smoothed off, and placed (on its large end) on a glass plate and the smaller

end smoothed off with a trowel; the paste, confined in the ring, resting on the plate, is placed under the rod bearing the cylinder, which is brought in contact with the surface and quickly released.

31. The paste is of normal consistency when the cylinder penetrates to a point in the mass 10 mm. (0.39 in.) below the top of the ring. Great care must be taken to fill the ring exactly to the top.

32. The trial pastes are made with varying percentages of water until the correct consistency is obtained.

NOTE. The Committee on Standard Specifications for Cement inserts the following table for temporary use to be replaced by one to be devised by the Committee of the American Society of Civil Engineers.

PERCENTAGE OF WATER FOR STANDARD SAND MORTARS.

Neat.	One Cement Three Standard Ottawa Sand.	Neat.	One Cement Three Standard Ottawa Sand.	Neat.	One Cement Three Standard Ottawa Sand.
15	8.0	23	9.3	31	10.7
16	8.2	24	9.5	32	10.8
17	8.3	25	9.7	33	11.0
18	8.5	26	9.8	34	11.2
19	8.7	27	10.0	35	11.5
20	8.8	28	10.2	36	11.5
21	9.0	29	10.3	37	11.7
22	9.2	30	10.5	38	11.8

	1 to 1	1 to 2	1 to 3	1 to 4	1 to 5
Cement...	500	333	250	200	167
Sand......	500	666	750	800	833

33. The Committee has recommended, as normal, a paste, the consistency of which is rather wet, because it

believes that variations in the amount of compression to which the briquette is subjected in molding are likely to be less with such a paste.

34. Having determined in this manner the proper percentage of water required to produce a paste of normal consistency, the proper percentage required for the mortars is obtained from an empirical formula.

35. The Committee hopes to devise such a formula. The subject proves to be a very difficult one, and, although the Committee has given it much study, it is not yet prepared to make a definite recommendation.

Time of Setting.

36. Significance. The object of this test is to determine the time which elapses from the moment water is added until the paste ceases to be fluid and plastic (called the "initial set"), and also the time required for it to acquire a certain degree of hardness (called the "final" or "hard set"). The former of these is the more important, since, with the commencement of setting, the process of crystallization or hardening is said to begin. As a disturbance of this process may produce a loss of strength, it is desirable to complete the operation of mixing and molding or incorporating the mortar into the work before the cement begins to set.

37. It is usual to measure arbitrarily the beginning and end of the setting by the penetration of weighted wires of given diameters.

38. Method. For this purpose the Vicat Needle, which has already been described in paragraph 29, should be used.

39. In making the test, a paste of normal consistency is molded and placed under the rod (*L*), Fig. 24, as described in paragraph 30; this rod, bearing the cap (*D*) at one end and the needle (*H*), 1 mm. (0.039 in.) in diameter, at the

other, weighing 300 gr. (10.58 oz.). The needle is then carefully brought in contact with the surface of the paste and quickly released.

40. The setting is said to have commenced when the needle ceases to pass a point 5 mm. (0.20 in.) above the upper surface of the glass plate, and is said to have terminated the moment the needle does not sink visibly into the mass.

41. The test pieces should be stored in moist air during the test; this is accomplished by placing them on a rack over water contained in a pan and covered with a damp cloth, the cloth to be kept away from them by means of a wire screen; or they may be stored in a moist box or closet.

42. Care should be taken to keep the needle clean, as the collection of cement on the sides of the needle retards the penetration, while cement on the point reduces the area and tends to increase the penetration.

43. The determination of the time of setting is only approximate, being materially affected by the temperature of the mixing water, the temperature and humidity of the air during the test, the percentage of water used, and the amount of molding the paste receives.

Standard Sand.

44. The Committee recognizes the grave objections to the standard quartz now generally used, especially on account of its high percentage of voids, the difficulty of compacting in the molds, and its lack of uniformity; it has spent much time in investigating the various natural sands which appeared to be available and suitable for use.

45. For the present, the Committee recommends the natural sand from Ottawa, Ill., screened to pass a sieve having 20 meshes per linear inch and retained on a sieve having 30 meshes per linear inch; the wires to have diameters of 0.0165 and 0.0112 in., respectively, *i.e.*, half the width of

the opening in each case. Sand having passed the No. 20 sieve shall be considered standard when not more than one per cent passes a No. 30 sieve after one minute continuous sifting of a 500-gram sample.

Form of Briquette.

46. While the form of the briquette recommended by a former Committee of the Society is not wholly satisfactory, this Committee is not prepared to suggest any change, other than rounding off the corners by curves of $\frac{1}{4}$-in. radius, Fig. 63.

Molds.

47. The molds should be made of brass, bronze, or some equally noncorrodible material, having sufficient metal in the sides to prevent spreading during molding.

48. Gang molds, which permit molding a number of briquettes at one time, are preferred by many to single molds, since the greater quantity of mortar that can be mixed tends to produce greater uniformity in the results. The type shown in Fig. 64 is recommended.

49. The molds should be wiped with an oily cloth before using.

Mixing.

50. All proportions should be stated by weight; the quantity of water to be used should be stated as a percentage of the dry material.

51. The metric system is recommended because of the convenient relation of the gram and the cubic centimeter.

52. The temperature of the room and the mixing water should be as near 21° Cent. (70° Fahr.) as it is practicable to maintain it.

53. The sand and cement should be thoroughly mixed dry. The mixing should be done on some nonabsorbing surface, preferably plate glass. If the mixing must be done

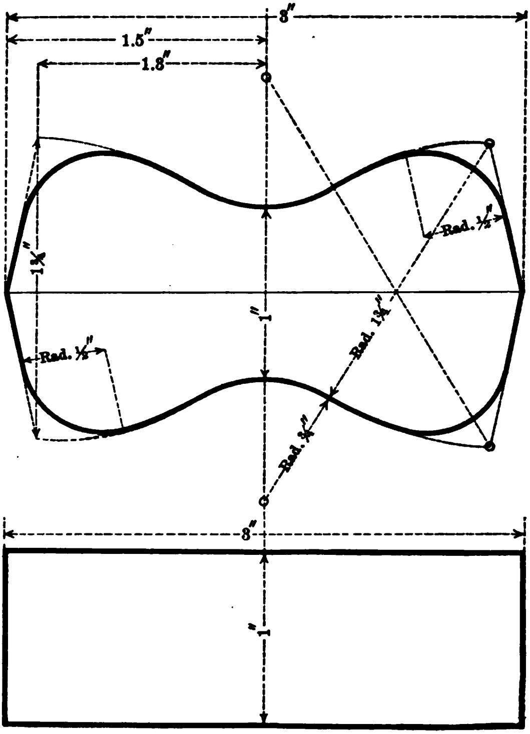

Fig. 63. — Details for Briquette

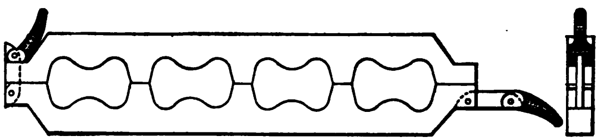

Fig. 64. — Details for Gang Mold

on an absorbing surface, it should be thoroughly dampened prior to use.

54. The quantity of material to be mixed at one time depends on the number of test pieces to be made; about 1000 gr. (35.28 oz.) makes a convenient quantity to mix, especially by hand methods.

55. The Committee, after investigation of the various mechanical mixing machines, has decided not to recommend any machine that has thus far been devised, for the following reasons: (1) The tendency of most cement is to "ball up" in the machine, thereby preventing the working of it into a homogeneous paste; (2) there are no means of ascertaining when the mixing is complete without stopping the machine; and (3) the difficulty of keeping the machine clean.

56. METHOD. The material is weighed and placed on the mixing table, and a crater formed in the center, into which the proper percentage of clean water is poured; the material on the outer edge is turned into the crater by the aid of a trowel. As soon as the water has been absorbed, which should not require more than 1 minute, the operation is completed by vigorously kneading with the hands for an additional $1\frac{1}{2}$ minutes, the process being similar to that used in kneading dough. A sandglass affords a convenient guide for the time of kneading. During the operation of mixing, the hands should be protected by gloves, preferably of rubber.

MOLDING.

57. Having worked the paste or mortar to the proper consistency, it is at once placed in the molds by hand.

58. The Committee has been unable to secure satisfactory results with the present molding machines; the operation of machine molding is very slow, and the present types permit of molding but one briquette at a time, and are not practicable with the pastes or mortars herein recommended.

59. METHOD. The molds should be filled immediately

after the mixing is completed, the material pressed in firmly with the fingers and smoothed off with a trowel without mechanical ramming. The mold should be turned over and the operation repeated.

60. A check upon the uniformity of the mixing and molding is afforded by weighing the briquettes just prior to immersion, or upon removal from the moist closet. Briquettes which vary in weight more than 3 per cent from the average should not be tested.

Storage of the Test Pieces.

61. During the first 24 hours after molding, the test pieces should be kept in moist air to prevent them from drying out.

62. A moist closet or chamber is so easily devised that the use of the damp cloth should be abandoned if possible. Covering the test pieces with a damp cloth is objectionable, as commonly used, because the cloth may dry out unequally, and, in consequence, the test pieces are not all maintained under the same condition. Where a moist closet is not available, a cloth may be used and kept uniformly wet by immersing the ends in water. It should be kept from direct contact with the test pieces by means of a wire screen or some similar arrangement.

63. A moist closet consists of a soapstone or slate box, or a metal-lined wooden box — the metal lining being covered with felt and this felt kept wet. The bottom of the box is so constructed as to hold water, and the sides are provided with cleats for holding glass shelves on which to place the briquettes. Care should be taken to keep the air in the closet uniformly moist.

64. After 24 hours in moist air the test pieces for longer periods of time should be immersed in water maintained as near 21° Cent. (70° Fahr.) as practicable; they may be stored in tanks or pans, which should be of noncorrodible material.

Tensile Strength.

65. The tests may be made on any standard machine. A solid metal clip, as shown in Fig. 65, is recommended. This clip is to be used without cushioning at the points of

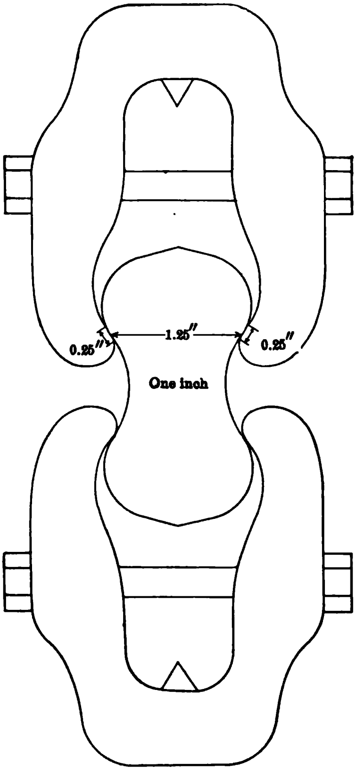

Fig. 65. — Form of Clip

contact with the test specimen. The bearing at each point of contact should be ¼-in. wide, and the distance between the center of contact on the same clip should be 1¼ ins.

66. Test pieces should be broken as soon as they are removed from the water. Care should be observed in centering the briquettes in the testing machine, as cross-strains, produced by improper centering, tend to lower the breaking strength. The load should not be applied too suddenly, as it may produce vibration, the shock from which often breaks the briquette before the ultimate strength is reached. Care must be taken that the clips and the sides of the briquette be clean and free from grains of sand or dirt, which would prevent a good bearing. The load should be applied at the rate of 600 lbs. per minute. The average of the briquettes of each sample tested should be taken as the test, excluding any results which are manifestly faulty.

Constancy of Volume.

67. Significance. The object is to develop those qualities which tend to destroy the strength and durability of a cement. As it is highly essential to determine such qualities at once, tests of this character are for the most part made in a very short time, and are known, therefore, as accelerated tests. Failure is revealed by cracking, checking, swelling, or disintegration, or all of these phenomena. A cement which remains perfectly sound is said to be of constant volume.

68. Methods. Tests for constancy of volume are divided into two classes: (1) normal tests, or those made in either air or water maintained at about 21° Cent. (70° Fahr.), and (2) accelerated tests, or those made in air, steam, or water at a temperature of 45° Cent. (115° Fahr.) and upward. The test pieces should be allowed to remain 24 hours in moist air before immersion in water or steam, or preservation in air.

69. For these tests, pats, about 7½ cm. (2.95 ins.) in diameter, 1¼ cm. (0.49 in.) thick at the center, and tapering to a thin edge, should be made, upon a clean glass plate

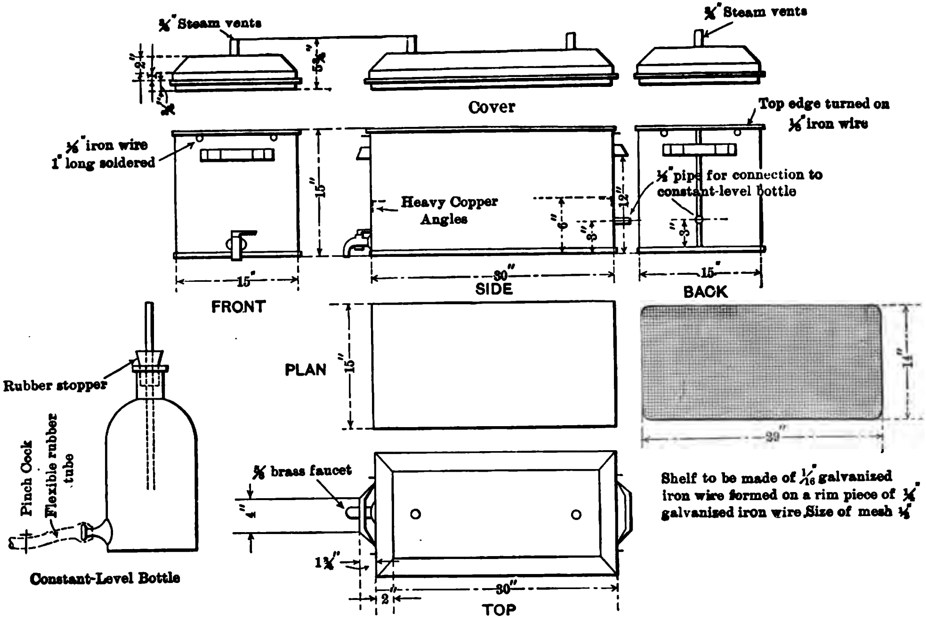

Fig. 66. — Details of Boiler for Accelerated Tests

Boiler is to be made of sheet copper weighing 22 oz. per sq. ft., turned inside. All seams to be lapped where possible. Only hard solder to be used.

[about 10 cm. (3.94 ins.) square], from cement paste of normal consistency.

70. Normal Test. A pat is immersed in water maintained as near 21° Cent. (70° Fahr.) as possible for 28 days, and observed at intervals. A similar pat, after 24 hours in moist air, is maintained in air at ordinary temperature and observed at intervals.

71. Accelerated Test. A pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely-closed vessel, for 5 hours. The apparatus recommended for making these determinations is shown in Fig. 66.

72. To pass these tests satisfactorily, the pats should remain firm and hard, and show no signs of cracking, distortion, or disintegration.

73. Should the pat leave the plate, distortion may be detected best with a straight-edge applied to the surface which was in contact with the plate.

74. In the present state of our knowledge it cannot be said that cement should necessarily be condemned simply for failure to pass the accelerated tests; nor can a cement be considered entirely satisfactory, simply because it has passed these tests.

APPENDIX II.

REPORT OF COMMITTEE ON STANDARD SPECIFICATIONS FOR CEMENT OF THE AMERICAN SOCIETY FOR TESTING MATERIALS.*

(ADOPTED BY THE SOCIETY, AUGUST 16, 1909.)

GENERAL OBSERVATIONS.

1. These remarks have been prepared with a view of pointing out the pertinent features of the various requirements and the precautions to be observed in the interpretation of the results of the tests.

2. The Committee would suggest that the acceptance or rejection under these specifications be based on tests made by an experienced person having the proper means for making the tests.

SPECIFIC GRAVITY.

3. Specific gravity is useful in detecting adulteration. The results of tests of specific gravity are not necessarily conclusive as an indication of the quality of a cement, but when in combination with the results of other tests may afford valuable indications.

FINENESS.

4. The sieves should be kept thoroughly dry.

TIME OF SETTING.

5. Great care should be exercised to maintain the test pieces under as uniform conditions as possible. A sudden

* Authorized reprint from Proceedings of the American Society for Testing Materials, Volume 9, 1909, pages 116–130.

change or wide range of temperature in the room in which the tests are made, a very dry or humid atmosphere, and other irregularities, vitally affect the rate of setting.

Constancy of Volume.

6. The tests for constancy of volume are divided into two classes, the first normal, the second accelerated. The latter should be regarded as a precautionary test only, and not infallible. So many conditions enter into the making and interpreting of it that it should be used with extreme care.

7. In making the pats the greatest care should be exercised to avoid initial strains due to molding or to too rapid drying-out during the first 24 hours. The pats should be preserved under the most uniform conditions possible, and rapid changes of temperature should be avoided.

8. The failure to meet the requirements of the accelerated tests need not be sufficient cause for rejection. The cement may, however, be held for 28 days, and a retest made at the end of that period. Failure to meet the requirements at this time should be considered sufficient cause for rejection, although in the present state of our knowledge it cannot be said that such failure necessarily indicates unsoundness, nor can the cement be considered entirely satisfactory simply because it passes the tests.

SPECIFICATIONS.

GENERAL CONDITIONS.

1. All cement shall be inspected.

2. Cement may be inspected either at the place of manufacture or on the work.

3. In order to allow ample time for inspecting and testing, the cement should be stored in a suitable weather-tight building having the floor properly blocked or raised from the ground.

4. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment.

5. Every facility shall be provided by the contractor, and a period of at least 12 days allowed for the inspection and necessary tests.

6. Cement shall be delivered in suitable packages with the brand and name of manufacturer plainly marked thereon.

7. A bag of cement shall contain 94 pounds of cement net. Each barrel of Portland cement shall contain 4 bags, and each barrel of natural cement shall contain 3 bags of the above net weight.

8. Cement failing to meet the 7-day requirements may be held awaiting the results of the 28-day tests before rejection.

9. All tests shall be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the Society January 21, 1903, and amended January 20, 1904, and January 15, 1908, with all subsequent amendments thereto.

10. The acceptance or rejection shall be based on the following requirements:

NATURAL CEMENT.

11. *Definition.* This term shall be applied to the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas.

Fineness.

12. It shall leave by weight a residue of not more than 10 per cent on the No. 100, and 30 per cent on the No. 200 sieve.

Time of Setting.

13. It shall not develop initial set in less than 10 minutes, and shall not develop hard set in less than 30 minutes, or in more than 3 hours.

Tensile Strength.

14. The minimum requirements for tensile strength for briquettes 1 square inch in cross section shall be as follows, and the cement shall show no retrogression in strength within the periods specified:

Age.	*Neat Cement.*	*Strength.*
24 hours in moist air		75 lbs.
7 days (1 day in moist air, 6 days in water)		150 "
28 days (1 day in moist air, 27 days in water)		250 "
	One Part Cement, Three Parts Standard Ottawa Sand.	
7 days (1 day in moist air, 6 days in water)		50 lbs.
28 days (1 day in moist air, 27 days in water)		125 "

Constancy of Volume.

15. Pats of neat cement about 3 inches in diameter, ½ inch thick at center, and tapering to a thin edge, shall be kept in moist air for a period of 24 hours.

(*a*) A pat is then kept in air at normal temperature.

(*b*) Another is kept in water maintained as near 70° Fahr. as practicable.

16. These pats are observed at intervals for at least 28 days, and, to satisfactorily pass the tests, should remain firm and hard and show no signs of distortion, checking, cracking, or disintegrating.

PORTLAND CEMENT.

17. *Definition.* This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3 per cent has been made subsequent to calcination.

Specific Gravity.

18. The specific gravity of cement shall be not less than 3.10. Should the test of cement as received fall below this requirement, a second test may be made upon a sample ignited at a low red heat. The loss in weight of the ignited cement shall not exceed 4 per cent.

Fineness.

19. It shall leave by weight a residue of not more than 8 per cent on the No. 100, and not more than 25 per cent on the No. 200 sieve.

Time of Setting.

20. It shall not develop initial set in less than 30 minutes, and must develop hard set in not less than 1 hour, nor more than 10 hours.

Tensile Strength.

21. The minimum requirements for tensile strength for briquettes 1 sq. in. in cross section shall be as follows, and the cement shall show no retrogression in strength within the periods specified:

Age.	*Neat Cement.*	*Strength.*
24 hours in moist air		175 lbs.
7 days (1 day in moist air, 6 days in water)		500 "
28 days (1 day in moist air, 27 days in water)		600 "

One Part Cement, Three Parts Standard Ottawa Sand.

Age.	*Strength.*
7 days (1 day in moist air, 6 days in water)..	200 lbs.
28 days (1 day in moist air, 27 days in water).	275 "

Constancy of Volume.

22. Pats of neat cement about 3 ins. in diameter, ½ in. thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of 24 hours.

(*a*) A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

(*b*) Another pat is kept in water maintained as near 70° Fahr. as practicable, and observed at intervals for at least 28 days.

(*c*) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for 5 hours.

23. These pats, to satisfactorily pass the requirements, shall remain firm and hard and show no signs of distortion, checking, cracking, or disintegrating.

Sulphuric Acid and Magnesia.

24. The cement shall not contain more than 1.75 per cent of anhydrous sulphuric acid (SO_3), nor more than 4 per cent of magnesia (MgO).

APPENDIX III.

METHOD SUGGESTED FOR THE ANALYSIS OF LIMESTONES, RAW MIXTURES, AND PORTLAND CEMENTS BY THE COMMITTEE ON UNIFORMITY IN TECHNICAL ANALYSIS OF THE NEW YORK SECTION OF THE SOCIETY FOR CHEMICAL INDUSTRY.*

SOLUTION.

One-half gram of the finely-powdered substance is to be weighed out and, if a limestone or unburned mixture, strongly ignited in a covered platinum crucible over a strong blast for 15 minutes, or longer if the blast is not powerful enough to effect complete conversion to a cement in this time. It is then transferred to an evaporating dish, preferably of platinum for the sake of celerity in evaporation, moistened with enough water to prevent lumping, and 5 to 10 c.c. of strong HCl added and digested with the aid of gentle heat and agitation until solution is complete. Solution may be aided by light pressure with the flattened end of a glass rod.† The solution is then evaporated to dryness, as far as this may be possible on the bath.

* Reprinted from Standard Methods of Testing and Specifications for Cement, edited by the Secretary, under the direction of Committee C on Standard Specifications of Cement of the American Society for Testing Materials.

† If anything remains undecomposed it should be separated, fused with a little Na_2CO_3, dissolved and added to the original solution. Of course a small amount of separated nongelatinous silica is not to be mistaken for undecomposed matter.

SILICA (SiO_2).

The residue without further heating is treated at first with 5 to 10 c.c. of strong HCl, which is then diluted to half strength or less, or upon the residue may be poured at once a larger volume of acid of half strength. The dish is then covered and digestion allowed to go on for 10 minutes on the bath, after which the solution is filtered and the separated silica washed thoroughly with water. The filtrate is again evaporated to dryness, the residue without further heating taken up with acid and water, and the small amount of silica it contains separated on another filter paper. The papers containing the residue are transferred wet to a weighed platinum crucible, dried, ignited, first over a Bunsen burner until the carbon of the filter is completely consumed, and finally over the blast for 15 minutes and checked by a further blasting for 10 minutes or to constant weight. The silica, if great accuracy is desired, is treated in the crucible with about 10 c.c. of HFl and 4 drops of H_2SO_4 and evaporated over a low flame to complete dryness. The small residue is finally blasted, for a minute or two, cooled and weighed. The difference between this weight and the weight previously obtained gives the amount of silica.*

ALUMINA AND IRON (Al_2O_3 AND Fe_2O_3).

The filtrate, about 250 c.c., from the second evaporation for SiO_2, is made alkaline with NH_4OH after adding HCl, if need be, to insure a total of 10 to 15 c.c. strong acid, and boiled to expel excess of NH_3, or until there is but a faint odor of it, and the precipitate iron and aluminum hydrates, after settling, are washed once by decantation and slightly on the filter. Setting aside the filtrate, the precipitate is dissolved in hot dilute HCl, the solution passing into the beaker in which the precipitation was made. The aluminum and

* For ordinary control in the plant laboratory this correction may, perhaps, be neglected; the double evaporation never.

iron are then reprecipitated by NH_4OH, boiled, and the second precipitate collected and washed on the same filter used in the first instance. The filter paper, with the precipitate, is then placed in a weighed platinum crucible, the paper burned off and the precipitate ignited and finally blasted 5 minutes, with care to prevent reduction, cooled, and weighed as $Al_2O_3 + Fe_2O_3$.*

IRON (Fe_2O_3).

The combined iron and aluminum oxides are fused in a platinum crucible at a very low temperature with about 3 to 4 grams of $KHSO_4$, or, better, $NaHSO_4$, the melt taken up with so much dilute H_2SO_4 that there shall be no less than 5 grams absolute acid and enough water to effect solution on heating. The solution is then evaporated and eventually heated till acid fumes come off copiously. After cooling and redissolving in water the small amount of silica is filtered out, weighed, and corrected by HFl and H_2SO_4.† The filtrate is reduced by zinc, or preferably by hydrogen sulphide, boiling out the excess of the latter afterwards while passing CO_2 through the flask, and titrated with permanganate.‡ The strength of the permanganate solution should not be greater than .0040 gr. Fe_2O_3 per c.c.

LIME (CaO).

To the combined filtrate from the $Al_2O_3 + Fe_2O_3$ precipitate a few drops of NH_4OH are added, and the solution brought to boiling. To the boiling solution 20 c.c. of a

* This precipitate contains TiO_2, P_2O_5, Mn_3O_4.

† This correction of $Al_2O_3Fe_2O_3$ for silica should not be made when the HFl correction of the main silica has been omitted, unless that silica was obtained by only one evaporation and filtration. After two evaporations and filtrations 1 to 2 mg. of SiO are still to be found with the $Al_2O_3Fe_2O_3$.

‡ In this way only is the influence of titanium to be avoided and a correct result obtained for iron.

saturated solution of ammonium oxalate are added, and the boiling continued until the precipitated CaC_2O_4, assumes a well-defined granular form. It is then allowed to stand for 20 minutes, or until the precipitate has settled, and then filtered and washed. The precipitate and filter are placed wet in a platinum crucible, and the paper burned off over a small flame of a Bunsen burner. It is then ignited, redissolved in HCl, and the solution made up to 100 c.c. with water. Ammonia is added in slight excess, and the liquid is boiled. If a small amount of Al_2O_3 separates, this is filtered out, weighed, and the amount added to that found in the first determination, when greater accuracy is desired. The lime is then reprecipitated by ammonium oxalate, allowed to stand until settled, filtered, and washed,* weighed as oxide by ignition and blasting in a covered crucible to constant weight, or determined with dilute standard permanganate.†

Magnesia (MgO).

The combined filtrates from the calcium precipitates are acidified with HCl and concentrated on the steam bath to about 150 c.c., 10 c.c. of saturated solution of $Na(NH_4)HPO_4$ are added, and the solution boiled for several minutes. It is then removed from the flame and cooled by placing the beaker in ice water. After cooling, NH_4OH is added drop by drop with constant stirring until the crystalline ammonium-magnesium orthophosphate begins to form, and then in moderate excess, the stirring being continued for several minutes. It is then set aside for several hours in a cool atmosphere and filtered. The precipitate is redissolved in hot dilute HCl, the solution made up to about 100 c.c., 1 c.c. of a saturated solution of $Na(NH_4)\ HPO_4$ added, and ammonia

* The volume of wash-water should not be too large; vide Hildebrand.

† The accuracy of this method admits of criticism, but its convenience and rapidity demand its insertion.

drop by drop, with constant stirring until the precipitate is again formed as described and the ammonia is in moderate excess. It is then allowed to stand for about 2 hours, when it is filtered on a paper or a Gooch crucible, ignited, cooled, and weighed as $Mg_2P_2O_7$.

Alkalies (K_2O and Na_2O).

For the determination of the alkalies, the well-known method of Prof. J. Lawrence Smith is to be followed, either with or without the addition of $CaCO_3$ with NH_4Cl.

Anhydrous Sulphuric Acid (SO_3).

One gram of the substance is dissolved in 15 c.c. of HCl, filtered, and residue washed thoroughly.*

The solution is made up to 250 c.c. in a beaker and boiled. To the boiling solution 10 c.c. of a saturated solution of $BaCl_2$ is added slowly drop by drop from a pipette and the boiling continued until the precipitate is well formed, or digestion on the steam bath may be substituted for the boiling. It is then set aside over night, or for a few hours filtered, ignited, and weighed as $BaSO_4$.

Total Sulphur.

One gram of the material is weighed out in a large platinum crucible and fused with Na_2CO_3 and a little KNO_3, being careful to avoid contamination from sulphur in the gases from source of heat. This may be done by fitting the crucible in a hole in an asbestos board. The melt is treated in the crucible with boiling water, and the liquid poured into a tall, narrow beaker and more hot water added until the mass is disintegrated. The solution is then filtered. The filtrate contained in a No. 4 beaker is to be acidulated with

* Evaporation to dryness is unnecessary, unless gelatinous silica should have separated and should never be performed on a bath heated by gas; vide Hildebrand.

HCl and made up to 250 c.c. with distilled water, boiled, the sulphur precipitated as $BaSO_4$ and allowed to stand over night or for a few hours.

Loss on Ignition.

Half a gram of cement is to be weighed out in a platinum crucible, placed in a hole in an asbestos board so that about $\frac{3}{5}$ of the crucible projects below, and blasted 15 minutes, preferably with an inclined flame. The loss by weight, which is checked by a second blasting of 5 minutes, is the loss on ignition.

May, 1903: Recent investigations have shown that large errors in results are often due to the use of impure distilled water and reagents. The analyst should, therefore, test his distilled water by evaporation and his reagents by appropriate tests before proceeding with his work.

APPENDIX IV.

MAJORITY REPORT OF PROGRESS REPORT OF SPECIAL COMMITTEE ON CONCRETE AND REINFORCED CONCRETE OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS.*

(PRESENTED AT THE BUSINESS MEETING OF THE ANNUAL CONVENTION, JULY 7, 1909.)

The report, herein presented, embodies the present judgment of the Committee concerning the proper use of Concrete and Reinforced Concrete.†

II. ADAPTABILITY OF CONCRETE AND REINFORCED CONCRETE.

The adaptability of concrete and reinforced concrete for engineering structures, or parts thereof, is now so well established that it may be considered one of the recognized materials of construction. It has proved to be a satisfactory material, when properly used, for those purposes for which its qualities make it particularly suitable.

1. *Proper Use.*

Concrete is a material of very low tensile strength and capable of sustaining but very small tensile deformations without rupture; its value as a structural material depends chiefly upon its durability, its fire-resisting qualities, its strength in compression, and its relatively low cost. Its strength increases generally with age.

* Authorized reprint from Trans. Am. Soc. C. E., Vol. 66, Mar., 1910.

† The larger part of *I. Introduction* is here omitted.

Plain concrete or massive concrete is well adapted for structural forms in which the principal stresses are compressive. These include foundations, dams, retaining and other walls, piers, abutments, short columns, and, in many cases, arches. In the design of massive concrete, the tensile strength of the material must generally be neglected.

By the use of metal reinforcement to resist the principal tensile stresses, concrete becomes available for general use in a great variety of structures and structural forms. This combination of concrete and metal is particularly advantageous in the beam, where both compression and tension exist; it is also advantageous in the column, where the main stresses are compressive, but where cross-bending may exist. In structures resisting lateral forces it possesses advantages over plain concrete in that it may be so designed as to utilize more fully the strength rather than the weight of the material.

2. *Improper Use.*

Failures of reinforced-concrete structures are usually due to any one or a combination of the following causes: defective design, poor material, and faulty execution.

The defects in the design may be many and various. The computations and assumptions on which they are based may be faulty and contrary to the established principles of statics and mechanics; the unit stresses used may be excessive, or the details of the design defective.

The design of reinforced-concrete structures should receive at least the same careful consideration as those of steel, and only engineers with sufficient experience and good judgment should be intrusted with such work.

The computations should include all minor details, which are sometimes of the utmost importance. The design should show clearly the size and position of the reinforcement, and should provide for proper connections

between the component parts, so that they cannot be displaced. As the connections between reinforced-concrete members are frequently a source of weakness, the design should include a detailed study of such connections, accompanied by computations to prove their strength.

The use of high unit stresses, approaching the danger line, is a defect in the design of reinforced-concrete structures.

Articulated concrete structures, designed in imitation of steel trusses, may be mentioned as illustrating a questionable use of reinforced concrete.

Poor material is sometimes used for concrete, as well as for the reinforcement. The use of inferior concrete is generally due to a lack of experience of the contractor and his superintendents, or to the absence of proper supervision.

An unsuitable quality of steel for reinforcement is sometimes prescribed in specifications, for the purpose of reducing the cost. For steel structures, a high grade of material is specified, while the steel used for reinforcing concrete is sometimes made of unsuitable, brittle material.

Faulty execution and careless workmanship may generally be attributed to unintelligent or insufficient supervision.

While other engineering structures, upon the safety of which human lives depend, are generally designed by engineers employed by the owner, and the contracts let on the engineer's design and specifications, in accordance with legitimate practice, reinforced-concrete structures frequently are designed by contractors or by engineers commercially interested, and the contract let for a lump sum, regardless of the merits of the design.

The construction of buildings in large cities is regulated by ordinances or building laws, and the work is inspected by municipal authorities. For reinforced-concrete work, however, the limited supervision which municipal inspectors are able to give is not sufficient. Means for more adequate supervision and inspection should, therefore, be provided.

3. *Responsibility and Supervision.*

The execution of the work should not be separated from the design, since intelligent supervision and successful execution can be expected only when both functions are combined. The engineer who prepares the design and specifications should therefore have the supervision of the execution of the work.

The Committee recommends the following rules for structures of reinforced concrete, for the purpose of fixing the responsibility and providing for adequate supervision during construction.

a. Before work is commenced, complete plans shall be prepared, accompanied by specifications, static computations, and descriptions showing the general arrangement and all details. The static computations shall give the loads assumed separately, such as dead and live loads, wind and impact, if any, and the resulting stresses.

b. The specifications shall state the qualities of the materials to be used for making the concrete, and the manner in which they are to be proportioned.

c. The strength which the concrete is expected to attain after a definite period shall be stated in the specifications.

d. The drawings and the specifications shall be signed by the engineer and the contractor.

e. The approval of plans and specifications by other authorities shall not relieve the engineer nor the contractor of responsibility.

f. Inspection during construction shall be made by competent inspectors employed by and under the supervision of the engineer and shall cover the following:

1. The materials.
2. The correct construction and erection of the forms and the supports.
3. The sizes, shapes, and arrangement of the reinforcement.

4. The proportioning, mixing, and placing of the concrete.
5. The strength of the concrete by tests of standard test pieces made on the work.
6. Whether the concrete is sufficiently hardened before the forms and supports are removed.
7. Prevention of injury to any part of the structure by and after the removal of the forms.
8. Comparison of dimensions of all parts of the finished structure with the plans.

g. Load tests on portions of the finished structure shall be made where there is reasonable suspicion that the work has not been properly performed, or that, through influences of some kind, the strength has been impaired. Loading shall be carried on to such a point that twice the calculated working stresses in critical parts are reached, and such loads shall cause no permanent deformations. Load tests shall not be made until after 60 days of hardening.

4. *Destructive Agencies.*

a. Corrosion of Metal Reinforcement. Tests and experience have proved that steel embedded in good concrete will not corrode, no matter whether located above or below fresh- or sea-water level. If the concrete is porous, so as to be readily permeable to water, as, where concrete is laid with a very dry consistency, the metal may be corroded in the presence of moisture.

b. Electrolysis. There is little accurate information available as to the effect of electrolysis on concrete. The few experiments that are available seem to indicate that concrete may be damaged through the leakage of small electrical currents through the mass, particularly where steel is embedded in the concrete. These experiments are not conclusive, however, and the large numbers of reinforced-concrete structures subject to the action of electroly-

sis, in which the metal and concrete are in perfect condition, would seem to indicate that the destructive action reported was due to abnormal conditions which do not often occur in practice.

c. Salt Water. The data available concerning the effect of sea water on concrete or reinforced concrete are inconclusive and limited in amount. There have been no authentic cases reported where the disintegration has proved to be due entirely to sea water. The decomposition that has been reported manifests itself in a number of ways; in some cases the mortar softens and crumbles; in others a crust forms which in time comes off. It has been found, however, that where concrete is proportioned in such a way as to secure a maximum density and is mixed thoroughly it makes an impervious concrete, upon which sea water has apparently little effect. Seawalls have been standing for considerable lengths of time without apparent injury. In many of our harbors where the water has been rendered brackish through rivers discharging into them, the action that has been reported has been at the water line and was probably due in part to freezing.

d. Acids. Concrete of first-class quality, thoroughly hardened, is affected appreciably only by strong acids which seriously injure other materials. A substance like manure, because of the acid in its composition, is injurious to green concrete, but after the concrete has thoroughly hardened it satisfactorily resists such action.

e. Oils. When concrete is properly made and the surface carefully finished and hardened it resists the action of such oils as petroleum and ordinary engine oils. Certain oils which contain fatty acids appear to produce injurious effects.

f. Alkalies. The action of alkalies on concrete is problematical. In the reclamation of arid land, where the soil is heavily charged with alkaline salts, it has been found that concrete, stone, brick, iron, and other materials are injured

under certain conditions. It would seem that at the level of the ground water such structures are disintegrated, possibly due to the effect of formation of crystals resulting from the alternate wetting and drying of the surface of the concrete at this ground-water line. Such action can be prevented by the use of an insulating coating.

III. Materials.

A knowledge of the properties of the materials entering into concrete and reinforced concrete is the first essential. The importance of the quality of the materials used cannot be overestimated, and, not only the cement, but also the aggregates, should be subject to such definite requirements and tests as will insure a concrete of the required quality.

1. *Cement.*

There are available, for construction purposes, Portland, Natural, and Puzzolan or Slag cements. Only Portland cement is suitable for reinforced concrete.

a. Portland Cement is the finely-pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly-proportioned, argillaceous and calcareous materials. It has a definite chemical composition varying within comparatively narrow limits.

Portland cement should be used in reinforced-concrete construction and any construction that will be subject to shocks or vibrations or stresses other than direct compression.

b. Natural Cement is the finely-pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas. While the limestone must have a certain composition, this composition may vary in much wider limits than in the case of Portland cement. Natural cement does not develop its strength as quickly nor is it as uniform in composition as Portland cement.

Natural cement may be used in massive masonry where weight rather than strength is the essential feature.

Where economy is the governing factor, a comparison may be made between the use of natural cement and a leaner mixture of Portland cement that will develop the same strength.

c. Puzzolan or Slag Cement is the finely-pulverized product resulting from grinding a mechanical mixture of granulated, basic, blast-furnace slag and hydrated lime.

Puzzolan cement is not nearly as strong, uniform, or reliable as Portland or natural cement, is not extensively used, and never in important work; it should be used only for foundation work underground where it is not exposed to air or running water.

d. Specifications. The cement should meet the requirements of the Standard Specifications for Cement (see Appendix II). A number of societies have been working on methods for testing and specifications for cement. The best practice seems to be represented in the standard methods of testing and specifications for cement which are the result of the joint labors of Special Committees of the American Society of Civil Engineers, American Society for Testing Materials, American Railway Engineering and Maintenance of Way Association, American Institute of Architects, and others.

2. *Aggregates.*

Extreme care should be exercised in selecting the aggregates for mortar and concrete, and careful tests made of the materials for the purpose of determining their qualities and the grading necessary to secure maximum density* or a minimum percentage of voids.

* A convenient coefficient of density is the ratio of the sum of the volumes of materials contained in a unit volume to the total unit volume.

a. Fine Aggregate consists of sand, crushed stone, or gravel screenings, passing when dry a screen having ¼-inch-diameter holes. It should be preferably of siliceous material, clean, coarse, free from vegetable loam or other deleterious matter.

A gradation of the grain from fine to coarse is generally advantageous. Mortars composed of one part Portland cement and three parts fine aggregate, by weight, when made into briquettes should show a tensile strength of at least 70 per cent of the strength of 1:3 mortar of the same consistency made with the same cement and standard Ottawa sand. To avoid the removal of any coating on the grains, which may affect the strength, bank sands should not be dried before being made into mortar, but should contain natural moisture. The percentage of moisture may be determined upon a separate sample for correcting weight. From 10 to 40 per cent more water may be required in mixing bank or artificial sands than standard Ottawa sand to produce the same consistency.

b. Coarse Aggregate consists of inert material, such as crushed stone, or gravel, which is retained on a screen having ¼-inch-diameter holes. The particles should be clean, hard, durable, and free from all deleterious material. Aggregates containing soft, flat, or elongated particles should be excluded from important structures. A graduation of sizes of the particles is generally advantageous.

The maximum size of coarse aggregate shall be such that it will not separate from the mortar in laying and will not prevent the concrete from fully surrounding the reinforcement and filling all parts of the forms. Where concrete is used in mass, the size of the coarse aggregate may be such as to pass a 3-in. ring. For reinforced-concrete members a size to pass a 1-in. ring, or a smaller size, may be used.

Cinder concrete is not suitable for reinforced-concrete structures, and may be safely used only in mass for very light loads or for fireproofing.

Where cinder concrete is permissible, the cinders used as the coarse aggregate should be composed of hard, clean, vitreous clinker, free from sulphides, unburned coal, or ashes.

3. *Water.*

The water used in mixing concrete should be free from oil, acid, strong alkalies, or vegetable matter.

4. *Metal Reinforcement.*

The Committee recommends, as a suitable material for reinforcement, steel filling the requirements of the specifications adopted by the American Railway Engineering and Maintenance of Way Association.

For the reinforcement of slabs, small beams, or minor details, or for the prevention of shrinkage cracks where wire or small rods are suitable, material conforming to the requirements of either Specification A or B given in the Appendix may be used.

The reinforcement should be free from rust, scale, or coatings of any character which would tend to reduce or destroy the bond.

IV. Preparation and Placing of Mortar and Concrete.

1. *Proportions.*

The materials to be used in concrete should be carefully selected, of uniform quality, and proportioned with a view to securing as nearly as possible a maximum density.

a. Unit of Measure. The unit of measure should be the barrel, which should be taken as containing 3.8 cu. ft. Four bags containing 94 lbs. of cement each should be considered the equivalent of one barrel. Fine and coarse aggregate should be measured separately as loosely thrown into the measuring receptacle.

b. Relation of Fine and Coarse Aggregates. The fine and coarse aggregates should be used in such relative proportions as will insure maximum density. In unimportant work it is sufficient to do this by individual judgment, using correspondingly higher proportions of cement; for important work these proportions should be carefully determined by density experiments, and the sizing of the fine and coarse aggregates should be uniformly maintained, or the proportions changed to meet the varying sizes.

c. Relation of Cement and Aggregates. For reinforced-concrete construction, a density proportion based on 1:6 should generally be used, *i.e.*, one part of cement to a total of six parts of fine and coarse aggregates measured separately.

In columns, richer mixtures are often required, while for massive masonry or rubble concrete a leaner mixture, of 1:9 or even 1:12, may be used. These proportions should be determined by the strength or wearing qualities required in the construction at the critical period of its use. Experienced judgment based on individual observation and tests of similar conditions in similar localities is the best guide as to the proper proportions for any particular case.

2. *Mixing.*

The ingredients of concrete should be thoroughly mixed to the desired consistency, and the mixing should continue until the cement is uniformly distributed and the mass is uniform in color and homogeneous, since the maximum density and therefore the greatest strength of a given mixture depends largely on thorough and complete mixing.

a. Measuring Ingredients. Methods of measurement of the proportions of the various ingredients, including the water, should be used, which will secure separate, uniform measurements at all times.

b. Machine Mixing. When the conditions will permit, a machine mixer of a type which insures the uniform pro-

portioning of the materials throughout the mass should be used, since a more thorough and uniform consistency can be thus obtained.

c. Hand Mixing. When it is necessary to mix by hand, the mixing should be on a water-tight platform, and especial precautions should be taken to turn the materials until they are homogeneous in appearance and color.

d. Consistency. The materials should be mixed wet enough to produce a concrete of such a consistency as will flow into the forms and about the metal reinforcement, and, at the same time, can be conveyed from the mixer to the forms without separation of the coarse aggregate from the mortar.

e. Retempering. Retempering mortar or concrete, *i.e.*, remixing with water after it has partially set, should not be permitted.

3. *Placing of Concrete.*

a. Methods. Concrete, after the addition of water to the mix, should be handled rapidly, and in as small masses as is practicable, from the place of mixing to the place of final deposit, and under no circumstances should concrete be used that has partially set before final placing. A slow-setting cement should be used when a long time is likely to occur between mixing and final placing.

The concrete should be deposited in such a manner as will permit the most thorough compacting, such as can be obtained by working with a straight shovel or slicing tool kept moving up and down until all the ingredients have settled in their proper place by gravity and the surplus water has been forced to the surface.

In depositing the concrete under water, special care should be exercised to prevent the cement from being floated away, and to prevent the formation of laitance which hardens very slowly and forms a poor surface on which to deposit fresh

concrete. Laitance is formed in both still and running water, and should be removed before placing fresh concrete.

Before placing the concrete, care should be taken to see that the forms are substantial and thoroughly wetted and the space to be occupied by the concrete is free from débris. When the placing of the concrete is suspended, all necessary grooves for joining future work should be made before the concrete has had time to set.

When work is resumed, concrete previously placed should be roughened, thoroughly cleansed of foreign material and laitance, drenched and slushed with a mortar consisting of one part Portland cement and not more than two parts fine aggregate.

The faces of concrete exposed to premature drying should be kept wet for a period of at least seven days.

b. Freezing Weather. Concrete for reinforced structures should not be mixed or deposited at a freezing temperature, unless special precautions are taken to avoid the use of materials containing frost or covered with ice crystals, and to provide means to prevent the concrete from freezing after being placed in position and until it has thoroughly hardened.

c. Rubble Concrete. Where the concrete is to be deposited in massive work, its value may be improved and its cost materially reduced through the use of clean stones thoroughly embedded in the concrete as near together as is possible and still entirely surrounded by concrete.

V. Forms.

Forms should be substantial and unyielding, so that the concrete shall conform to the designed dimensions and contours, and should be tight to prevent the leakage of mortar.

The time for removal of forms is one of the most important steps in the erection of a structure of concrete or reinforced concrete. Care should be taken to inspect the concrete and ascertain its hardness before removing the forms.

So many conditions affect the hardening of concrete that the proper time for the removal of the forms should be decided by some competent and responsible person, especially where the atmospheric conditions are unfavorable.

VI. Details of Construction.

1. *Joints.*

a. Reinforcement. Wherever in tension reinforcement it is necessary to splice the reinforcing bars, the length of lap shall be determined on the basis of the safe bond stress and the stress in the bar at the point of splice; or a connection shall be made between the bars of sufficient strength to carry the stress. Splices at points of maximum stress should be avoided. In columns, large bars should be properly butted and spliced; small bars may be treated as indicated for tension reinforcement, or their stress may be taken off by being embedded in large masses of concrete. At foundations, bearing plates should be provided for large bars or structural forms.

b. Concrete. For concrete construction it is desirable to cast the entire structure at one operation, but as this is not always possible, especially in large structures, it is necessary to stop the work at some convenient point. This point should be selected so that the resulting joint may have the least possible effect on the strength of the structure. It is therefore recommended that the joints in columns be made flush with the lower side of the girders; that the joints in girders be at a point midway between supports, but should a beam intersect a girder at this point, the joint should be offset a distance equal to twice the width of the beam; that the joints in the members of a floor system should in general be made at or near the center of the span.

Joints in columns should be perpendicular to the axis of the column, and in girders, beams, and floor slabs perpendicular to the plane of their surfaces.

2. *Shrinkage.*

Girders should never be constructed over freshly formed columns without permitting a period of at least two hours to elapse, thus providing for settlement or shrinkage in the columns. Before resuming work, the top of the column should be thoroughly cleansed of foreign matter and laitance. If the concrete in the column has become hard, the top should also be drenched and slushed with a mortar consisting of one part Portland cement and not more than two parts fine aggregate before placing additional concrete.

3. *Temperature Changes.*

Concrete is sensitive to temperature changes, and it is necessary to take this fact into account in designing and erecting concrete structures. In some positions the concrete is subjected to a much greater fluctuation in temperature than in others, and in such cases joints are necessary. The frequency of these joints will depend, first, upon the range of temperature to which concrete will be subjected; second, upon the quantity and position of the reinforcement. These points should be determined and provided for in the design. In massive work, such as retaining walls, abutments, etc., built without reinforcement, joints should be provided, approximately, every 50 ft. throughout the length of the structure. To provide against the structures being thrown out of line by unequal settlement, each section of the wall may be tongued and grooved into the adjoining section. To provide against unsightly cracks, due to unequal settlement, a joint should be made at all sharp angles.

4. *Fireproofing.*

The actual fire tests of concrete and reinforced concrete have been limited, but experience, together with the results of tests so far made, indicate that concrete may be safely

used for fireproofing purposes. Concrete itself is incombustible and reasonably proof against fire when composed of a siliceous sand and a hard, coarse aggregate such as igneous rock.

For a fireproof covering, these same materials may be used, or clean, hard-burned cinders may be substituted for the coarse aggregate.

The low rate of heat conductivity of concrete is one reason of its value for fireproofing. The dehydration of the water of crystallization of concrete probably begins at about 500° Fahr., and is completed at about 900° Fahr., but experience indicates that the volatilization of the water absorbs heat from the surrounding mass, which, together with the resistance of the air cells, tends to increase the heat resistance of the concrete, so that the process of dehydration is very much retarded. The concrete that is actually affected by fire remains in position and affords protection to the concrete beneath it.

It is recommended that in monolithic concrete columns, the concrete to a depth of 1½ in. be considered as protective covering and not included in the effective section.

The thickness of the protective coating required depends upon the probable duration of a fire which is likely to occur in the structure, and should be based on the rate of heat conductivity. The question of the conductivity of concrete is one which requires further study and investigation before a definite rate for different classes of concrete can be fully established. However, for ordinary conditions it is recommended that the metal in girders and columns be protected by a minimum of 2 in. of concrete; that the metal in beams be protected by a minimum of 1½ in. of concrete, and that the metal in floor slabs be protected by a minimum of 1 in. of concrete.

It is recommended that the corners of columns, girders, and beams be beveled or rounded, as a sharp corner is more seriously affected by fire than a round one.

5. *Waterproofing.*

Many expedients have been used to render concrete impervious to water under normal conditions, and also under pressure conditions that exist in reservoirs, dams, and conduits of various kinds. Experience shows, however, that where mortar or concrete is proportioned to obtain the greatest practicable density and is mixed to a rather wet consistency, the resulting mortar or concrete is impervious under ordinary conditions. A concrete of dry consistency is more or less pervious to water, and compounds of various kinds have been mixed with the concrete, or applied as a wash to the surface for the purpose of making it water-tight. Many of these compounds are of but temporary value, and in time lose their power of imparting impermeability to the concrete.

In the case of subways, long retaining walls, and reservoirs, leakage cracks may be prevented by horizontal and vertical reinforcement, properly proportioned and located, provided the concrete itself is impervious.

Such reinforcement distributes the stretch due to contraction or settlement so that the cracks are too minute to permit leakage, or are soon closed by infiltration of silt.

Asphaltic or coal-tar preparations, applied either as a mastic or as a coating on felt or cloth fabric, are used for waterproofing, and should be proof against injury by liquids or gases.

6. *Surface Finish.*

Concrete is a material of an individual type, and should not be used in imitation of other structural materials. One of the important problems connected with the use of concrete is the character of the finish of exposed surfaces. The finish of the surface should be determined before the concrete is placed, and the work conducted so as to make possible the finish desired. For many forms of construction the

natural surface of the concrete is unobjectionable, but frequently the marks of the boards and the flat, dead surface are displeasing, and make some special treatment desirable. A treatment of the surface which removes the film of mortar and brings the coarser particles of the concrete into relief is frequently used to remove the form markings, break the monotonous appearance of the surface, and make it more pleasing. Plastering of surfaces should be avoided, for the other methods of treatment are more reliable and usually much more satisfactory. Plastering, even if carefully applied, is likely to peel off under the action of frost or temperature changes.

VII. Design.

1. *Massive Concrete.*

In the design of massive concrete or plain concrete, no account should be taken of the tensile strength of the material, and sections should usually be so proportioned as to avoid tensile stresses. This will generally be accomplished, in the case of rectangular shapes, if the line of pressure is kept within the middle third of the section, but in very large structures, such as high masonry dams, a more exact analysis may be required. Structures of massive concrete are able to resist unbalanced lateral forces by reason of their weight, hence the element of weight rather than strength often determines the design. A relatively cheap and weak concrete will therefore often be suitable for massive concrete structures. Owing to its low extensibility, the contraction due to hardening and to temperature changes requires special consideration, and, except in the case of very massive walls such as dams, it is desirable to provide joints at intervals to localize the effect of such contraction. The spacing of such joints will depend upon the form and dimensions of the structure and its degree of exposure.

Massive concrete may well be used for piers and short columns, in which the ratio of length to least width is relatively small. Under ordinary conditions this ratio should not exceed six, but, where the central application of the load is assured, a somewhat higher value may safely be used.

Massive concrete is also a suitable material for arches of moderate span where the conditions as to foundations are favorable.

2. *Reinforced Concrete.*

By the use of metal reinforcement to resist the principal tensile stresses, concrete becomes available for general use in a great variety of structures and structural forms. This combination of concrete and steel is particularly advantageous in the beam, where both compression and tension exist; it is also advantageous in the column, where the main stresses are compressive, but where cross-bending may exist. The theory of design will therefore relate mainly to the analysis of beams and columns.

3. *General Assumptions.*

a. Loads. The loads or forces to be resisted consist of:

1. The dead load, which includes the weight of the structure and fixed loads and forces.
2. The live load, or the loads and forces which are variable. The dynamic effect of the live load will often require consideration. Any allowance for the dynamic effect is preferably taken into account by adding the desired amount to the live load or to the live-load stresses. The working stresses hereinafter recommended are intended to apply to the equivalent static stresses so determined.

   In the case of high buildings the live load on columns may be reduced in accordance with the usual practice.

b. Lengths of Beams and Columns. The span length for beams and slabs shall be taken as the distance from center to center of supports, but shall not be taken to exceed the clear span plus the depth of beam or slab. Brackets shall not be considered as reducing the clear span in the sense here intended.

The length of columns shall be taken as the maximum unsupported length.

c. Internal Stresses. As a basis for calculations relating to the strength of structures, the following assumptions are recommended:

1. Calculations should be made with reference to working stresses and safe loads rather than with reference to ultimate strength and ultimate loads.
2. A plane section before bending remains plane after bending.
3. The modulus of elasticity of concrete in compression, within the usual limits of working stresses, is constant. The distribution of compressive stresses in beams is therefore rectilinear.
4. In calculating the moment of resistance of beams the tensile stresses in the concrete shall be neglected.
5. Perfect adhesion is assumed between concrete and reinforcement. Under compressive stresses the two materials are therefore stressed in proportion to their moduli of elasticity.
6. The ratio of the modulus of elasticity of steel to the modulus of elasticity of concrete may be taken at 15.
7. Initial stress in the reinforcement due to contraction or expansion in the concrete may be neglected.

It is appreciated that the assumptions herein given are not entirely borne out by experimental data. They are given in the interest of simplicity and uniformity, and variations from exact conditions are taken into account in the selection of formulas and working stresses.

For calculations relative to deflections, the tensile strength of the concrete should be taken into account. For such calculations, also, a value of 8 to 12 for the ratio of the moduli corresponds more nearly to the actual conditions and may well be used.

4. *T-Beams.*

In beam and slab construction, an effective bond should be provided at the junction of the beam and slab. When the principal slab reinforcement is parallel to the beam, transverse reinforcement should be used extending over the beam and well into the slab.

Where adequate bond between slab and web of beam is provided, the slab may be considered as an integral part of the beam, but its effective width shall be determined by the following rules:

a. It shall not exceed one-fourth of the span length of the beam;

b. Its overhanging width on either side of the web shall not exceed 4 times the thickness of the slab.

In the design of T-beams acting as continuous beams, due consideration should be given to the compressive stresses at the support.

5. *Floor Slabs.*

Floor slabs should be designed and reinforced as continuous over the supports. If the length of the slab exceeds 1.5 times its width the entire load should be carried by

transverse reinforcement. Square slabs may well be reinforced in both directions.*

The loads carried to beams by slabs which are reinforced in two directions will not be uniformly distributed to the supporting beam, and may be assumed to vary in accordance with the ordinates of a triangle. The moments in the beams should be calculated accordingly.

6. *Continuous Beams and Slabs.*

When the beam or slab is continuous over its supports, reinforcement should be fully provided at points of negative moment. In computing the positive and negative moments in beams and slabs continuous over several supports, due

* The exact distribution of load on square and rectangular slabs, supported on four sides and reinforced in both directions, cannot readily be determined. The following method of calculation is recognized to be faulty, but it is offered as a tentative method which will give results on the safe side. The distribution of load is first to be determined by the formula

$$r = \frac{l^4}{l^4 + b^4},$$

in which r = proportion of load carried by the transverse reinforcement, l = length, and b = breadth of slab. For various ratios of l/b the values of r are as follows:

l/b	r
1	0.50
1.1	0.59
1.2	0.67
1.3	0.75
1.4	0.80
1.5	0.83

Using the values above specified, each set of reinforcement is to be calculated in the same manner as slabs having supports on two sides only, but the total amount of reinforcement thus determined may be reduced 25 per cent by gradually increasing the rod spacing from the third point to the edge of the slab.

to uniformly distributed loads, the following rules are recommended:

a. That for floor slabs the bending moments at center and at support be taken at $\frac{wl^2}{12}$ for both dead and live loads, where w represents the load per linear foot and l the span length.

b. That for beams the bending moment at center and at support for interior spans be taken at $\frac{wl^2}{12}$, and for end spans it be taken at $\frac{wl^2}{10}$ for center and adjoining support for both dead and live loads.

In the case of beams and slabs continuous for two spans only, or of spans of unusual length, more exact calculations should be made. Special consideration is also required in the case of concentrated loads.

Where beams are reinforced on the compression side, the steel may be assumed to carry its proportion of stress in accordance with the provisions of Section VII, Art. 3, *c*, paragraph 6. In the case of continuous beams, tensile and compressive reinforcement over supports must extend sufficiently beyond the support to develop the requisite bond strength.

7. *Bond Strength and Spacing of Bars.*

Adequate bond strength should be provided in accordance with the formula hereinafter given. Where a portion of the bars is bent up near the end of a beam, the bond stress in the remaining straight bars will be less than is represented by the theoretical formula.

Where high bond resistance is required, the deformed bar is a suitable means of supplying the necessary strength. Adequate bond strength throughout the length of a bar is

preferable to end anchorage, but such anchorage may properly be used in special cases. Anchorage furnished by short bends at a right angle is less effective than hooks consisting of turns through 180 degrees.

The lateral spacing of parallel bars should not be less than two and one-half diameters, center to center, nor should the distance from the side of the beam to the center of the nearest bar be less than two diameters. The clear spacing between two layers of bars should not be less than ½ in.

8. *Shear and Diagonal Tension.*

Calculations for web resistance shall be made on the basis of maximum shearing stress as determined by the formulas hereinafter given. When the maximum shearing stresses exceed the value allowed for the concrete alone, web reinforcement must be provided to aid in carrying the diagonal tension stresses. This web reinforcement may consist of bent bars, or inclined or vertical members attached to or looped about the horizontal reinforcement. Where inclined members are used, the connection to the horizontal reinforcement shall be such as to insure against slip.

Experiments bearing on the design of details of web reinforcement are not yet complete enough to allow more than general and tentative recommendations to be made. It is well established, however, that a very moderate amount of reinforcement, such as is furnished by a few bars bent up at small inclination, increases the strength of a beam against failure by diagonal tension to a considerable degree; and that a sufficient amount of web reinforcement can readily be provided to increase the shearing resistance to a value from three or more times that found when the bars are all horizontal and no web reinforcement is used. The following allowable values for the maximum shearing stress are therefore recommended, based on the working stresses of Section VIII, page 233.

a. For beams with horizontal bars, only 40 lbs. per sq. in.

b. For beams in which a part of the horizontal reinforcement is used in the form of bent-up bars, arranged with due respect to the shearing stresses, a higher value may be allowed, but not to exceed 60 lbs. per sq. in.

c. For beams thoroughly reinforced for shear, a value not exceeding 120 lbs. per sq. in.

In the calculation of web reinforcement to provide the strength required under *c*, the concrete may be counted upon as carrying one-third of the shear. The remainder is to be provided for by means of metal reinforcement consisting of bent rods or stirrups, but preferably both. The requisite amount of such reinforcement may be estimated on the assumption that the entire shear on a section, less the amount assumed to be carried by the concrete, is carried by the reinforcement in a length of beam equal to its depth.

The longitudinal spacing of stirrups or bent rods shall not exceed three-fourths the depth of the beam.

It is important that adequate bond strength be provided to develop fully the assumed strength of all shear reinforcement.

Inasmuch as small deformations in the horizontal steel tend to prevent the formation of diagonal cracks, a beam will be strengthened against diagonal tension failure by so arranging the horizontal reinforcement that the unit stresses at points of large shear shall be relatively low.

9. *Columns.*

It is recommended that the ratio of the unsupported length of a column to its least width be limited to 15.

The effective area of the column shall be taken as the area within the protective covering, as defined in Section VI, Art. 4; or, in the case of hooped columns or columns rein-

forced with structural shapes, it shall be taken as the area within the hooping or structural shapes.

Columns may be reinforced by means of longitudinal rods, by bands or hoops, by bands or hoops together with longitudinal bars, or by structural forms which in themselves are sufficiently rigid to act as columns. The general effect of bands or hoops is to increase greatly the "toughness" of the column and its ultimate strength, but hooping has little effect upon its behavior within the limit of elasticity. It thus renders the concrete a safer and more reliable material, and should permit the use of a somewhat higher working stress. The beneficial effects of "toughening" are adequately provided by a moderate amount of hooping, a larger amount serving mainly to increase the ultimate strength and the possible deformation before ultimate failure.

The following recommendations are made for the relative working stresses in the concrete for the several types of columns:

a. Columns with longitudinal reinforcement only, the unit stress recommended for axial compression in Section VIII, Article 3.

b. Columns with reinforcement of bands or hoops, as hereinafter specified, stresses 20 per cent higher than given for *a*.

c. Columns reinforced with not less than 1 per cent and not more than 4 per cent of longitudinal bars and with bands or hoops, stresses 45 per cent higher than given for *a*.

d. Columns reinforced with structural steel column units which thoroughly encase the concrete core, stresses 45 per cent higher than given for *a*.

In all cases, longitudinal steel is assumed to carry its proportion of stress in accordance with Article 3. The hoops or bands are not to be counted upon directly as adding to the strength of the column.

Bars composing longitudinal reinforcement shall be straight, and shall have sufficient lateral support to be securely held in place until the concrete has set.

Where bands or hoops are used, the total amount of such reinforcement shall not be less than 1 per cent of the volume of the column disclosed. The clear spacing of such bands or hoops shall not be greater than one-fourth the diameter of the enclosed column. Adequate means must be provided to hold bands or hoops in place so as to form a column, the core of which shall be straight and well centered.

Bending stresses due to eccentric loads must be provided for by increasing the section until the maximum stress does not exceed the values above specified.

10. *Reinforcing for Shrinkage and Temperature Stresses.*

Where large areas of concrete are exposed to atmospheric conditions, the changes of form due to shrinkage (resulting from hardening) and to action of temperature are such that large cracks will occur in the mass, unless precautions are taken to so distribute the stresses as either to prevent the cracks altogether or to render them very small. The size of the cracks will be directly proportional to the diameter of the reinforcing bars and inversely proportional to the percentage of reinforcement and also to its bond resistance per unit of surface area. To be most effective, therefore, reinforcement should be placed near the surface and well distributed, and a form of reinforcement used which will develop a high bond resistance.

VIII. Working Stresses.

1. *General Assumptions.*

The following working stresses are recommended for static loads. Proper allowances for vibration and impact are to be added to live loads where necessary to produce

an equivalent static load before applying the unit stresses in proportioning parts.

In selecting the permissible working stress to be allowed on concrete, we should be guided by the working stresses usually allowed for other materials of construction, so that all structures of the same class, but composed of different materials, may have approximately the same degree of safety.

The stresses for concrete are proposed for concrete composed of one part Portland cement and six parts of aggregates, capable of developing an average compressive strength of 2000 lbs. per sq. in. at 28 days, when tested in cylinders 8 in. in diameter and 16 in. long, under laboratory conditions of manufacture and storage, using the same consistency as is used in the field. In considering the factors recommended with relation to this strength, it is to be borne in mind that the strength at 28 days is by no means the ultimate which will be developed at a longer period, and therefore they do not correspond with the real factor of safety. On concretes, in which the material of the aggregate is inferior, all stresses should be proportionally reduced, and similar reduction should be made when leaner mixes are to be used. On the other hand, if, with the best quality of aggregates, the richness is increased, an increase may be made in all working stresses proportional to the increase in compressive strength at 28 days, but this increase shall not exceed 25 per cent.

2. *Bearing.*

When compression is applied to a surface of concrete larger than the loaded area, a stress of 32.5 per cent of the compressive strength at 28 days, or 650 lbs. per sq. in. on the above-described concrete, may be allowed. This pressure is probably unnecessarily low when the ratio of the stressed area to the whole area of the concrete is much

below unity, but is recommended for general use rather than a variable unit based upon this ratio.

3. *Axial Compression.*

For concentric compression on a plain concrete column or pier, the length of which does not exceed 12 diameters 22.50 per cent of the compressive strength at 28 days, or 450 lbs. per sq. in. on 2000-lb. concrete, may be allowed.

For other forms of columns, the stresses obtained from the ratios given in Section VII, Article 9, may govern.

4. *Compression in Extreme Fiber.*

The extreme fiber stress of a beam, calculated on the assumption of a constant modulus of elasticity for concrete under working stresses, may be allowed to reach 32.5 per cent of the compressive strength at 28 days, or 650 lbs. per sq. in. for 2000-lb. concrete. Adjacent to the support of continuous beams, stresses 15 per cent higher may be used.

5. *Shear and Diagonal Tension.*

Where pure shearing stress occurs, that is, uncombined with compression normal to the shearing surface, and with all tension normal to the shearing plane provided for reinforcement, a shearing stress of 6 per cent of the compressive strength at 28 days, or 120 lbs. per sq. in., on 2000-lb. concrete, may be allowed. Where the shear is combined with an equal compression, as on a section of a column at 45 degrees with the axis, the stress may equal one-half the compressive stress allowed. For ratios of compressive stress to shear intermediate between 0 and 1, proportionate shearing stresses shall be used.

In calculations on beams in which diagonal tension is considered to be taken by the concrete, the vertical shearing stresses should not exceed 2 per cent of the compressive strength at 28 days, or 40 lbs. per sq. in. for 2000-lb. concrete.

6. *Bond.*

The bonding stress between concrete and plain reinforcing bars may be assumed at 4 per cent of the compressive strength at 28 days, or 80 lbs. per sq. in. for 2000-lb. concrete; in the case of drawn wire, 2 per cent or 40 lbs. on 2000-lb. concrete.

7. *Reinforcement.*

The tensile stress in steel should not exceed 16,000 lbs. per sq. in. The compressive stress in reinforcing steel should not exceed 16,000 lbs. per sq. in., or 15 times the working compressive stress in the concrete.

In structural steel members, the working stresses adopted by the American Railway Engineering and Maintenance of Way Association are recommended.

8. *Modulus of Elasticity.*

The value of the modulus of elasticity of concrete has a wide range, depending upon the materials used, the age, the range of stresses between which it is considered, as well as other conditions. It is recommended that in all computations it be assumed as one-fifteenth that of steel, as, while not rigorously accurate, this assumption will give safe results.

RICHARD L. HUMPHREY,
Secretary.

JANUARY, 1909.

W. K. HATT, A. N. TALBOT,
R. W. LESLEY, J. W. SCHAUB,
J. R. WORCESTER.

APPENDIX V.

STANDARD SPECIFICATIONS OF THE AMERICAN SOCIETY FOR TESTING MATERIALS FOR STRUCTURAL STEEL FOR BRIDGES.*

(ADOPTED BY THE SOCIETY, AUGUST 16, 1909.)

1. MANUFACTURE. Steel shall be made by the open-hearth process.

2. CHEMICAL COMPOSITION. The chemical and physical properties shall conform to the following limits:

Elements Considered.	Structural Steel.	Rivet Steel.	Steel Castings.
Phosphorus, max. Basic	0.04 per cent	0.04 per cent	0.05 per cent
Phosphorus, max. Acid	0.06 per cent	0.04 per cent	0.08 per cent
Sulphur, max.	0.05 per cent	0.04 per cent	0.05 per cent
Ultimate tensile strength, Pounds per sq. in.	Desired 60,000	Desired 50,000	Not less than 65,000
Elongation: Min. per cent in 8 ins. (Fig. 67)	$\frac{1,500,000^*}{\text{Ult. tens. str.}}$	$\frac{1,500,000}{\text{Ult. tens. str.}}$	
Elongation: Min. per cent in 2 in. (Fig. 68)	22	....	18
Character of fracture	Silky	Silky	Silky or fine granular
Cold bend without fracture	180° flat †	180° flat‡	90° $d=3t$

* See par. 11. † See pars. 12, 13, and 14. ‡ See par. 15.

The yield point, as indicated by the drop of beam, shall be recorded in the test reports.

3. RETESTS. If the ultimate strength varies more than 4000 lbs. from that desired, a retest may be made at the

* Authorized reprint from Proceedings of the American Society for Testing Materials, Vol. 9, pages 37–41.

discretion of the inspector, on the same gauge, which to be acceptable shall be within 5000 lbs. of the desired ultimate.

4. Chemical Composition. Chemical determinations of the percentages of carbon, phosphorus, sulphur, and manganese shall be made by the manufacturer from a test ingot taken at the time of the pouring of each melt of steel, and a correct copy of such analysis shall be furnished to the engineer or his inspector. Check analyses shall be made from finished material, if called for by the purchaser, in which case an excess of 25 per cent above the required limits will be allowed.

5. Plates, Shapes, and Bars. Specimens for tensile and bending tests for plates, shapes, and bars shall be made by cutting coupons from the finished product, which shall have both faces rolled and both edges milled to the form shown in Fig. 67; or with both edges parallel, or they may

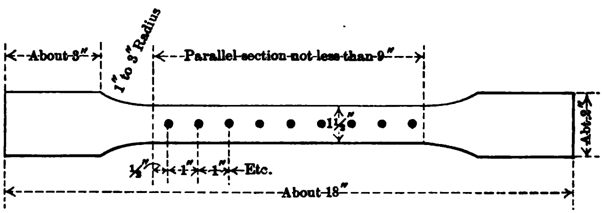

Fig. 67. — Flat Test Piece

be turned to a diameter of ¾ in. for a length of at least 9 ins., with enlarged ends.

6. Rivets. Rivet rods shall be tested as rolled.

7. Pins and Rollers. Specimens shall be cut from the finished rolled or forged bar in such a manner that the center of the specimen shall be 1 in. from the surface of the bar. The specimen for tensile test shall be turned to the form shown by Fig. 68. The specimen for bending test shall be 1 in. by ½ in. in section.

8. Steel Castings. The number of tests will depend on the character and importance of the castings. Speci-

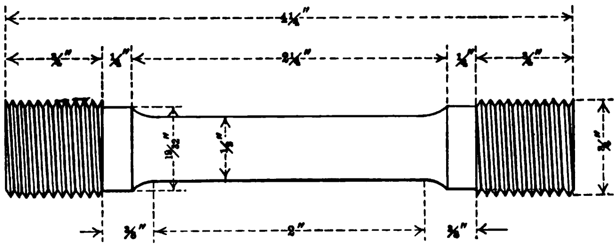

Fig. 68. — Small Turned Test Piece

mens shall be cut cold from coupons molded and cast on some portion of one or more castings from each melt or from the sink heads, if the heads are of sufficient size. The coupon or sink head, so used, shall be annealed with the casting before it is cut off. Test specimens to be of the form prescribed for pins and rollers.

9. Conditions for Tests. Material which is to be used without annealing or further treatment shall be tested in the condition in which it comes from the rolls. When material is to be annealed or otherwise treated before use, the specimens for tensile tests representing such material shall be cut from properly annealed or similarly-treated short lengths of the full section of the bar.

10. Number of Tests. At least one tensile and one bending test shall be made from each melt of steel as rolled. In case steel differing $\frac{3}{8}$ in. and more in thickness is rolled from one melt, a test shall be made from the thickest and thinnest material rolled.

11. Elongation. For material less than $\frac{5}{16}$ in. and more than $\frac{3}{4}$ in. in thickness the following modifications will be allowed in the requirements for elongation:

(*a*) For each $\frac{1}{16}$ in. in thickness below $\frac{5}{16}$ in., a deduction of $2\frac{1}{2}$ will be allowed from the specified percentage.

(*b*) For each $\frac{1}{8}$ in. in thickness above $\frac{3}{4}$ in., a deduction of 1 will be allowed from the specified percentage.

12. BENDING TESTS. Bending tests may be made by pressure or by blows. Plates, shapes, and bars less than 1 in. thick shall bend as called for in paragraph 2.

13. FULL-SIZED BENDS. Full-sized material for eyebars and other steel 1 in. thick and over, tested as rolled, shall bend cold 180 degrees around a pin the diameter of which is equal to twice the thickness of the bar, without fracture on the outside of bend.

14. TESTS FOR ANGLES. Angles $\frac{3}{4}$ in. and less in thickness shall open flat, and angles $\frac{1}{2}$ in. and less in thickness shall bend shut, cold, under blows of a hammer, without sign of fracture. This test will be made only when required by the inspector.

15. TESTS ON RIVET STEEL. Rivet steel, when nicked and bent around a bar of the same diameter as the rivet rod, shall give a gradual break and a fine, silky, uniform fracture.

16. FINISH. Finished material shall be free from injurious seams, flaws, cracks, defective edges, or other defects, and have a smooth, uniform, workmanlike finish. Plates 36 ins. in width and under shall have rolled edges.

17. MARKING. Every finished piece of steel shall have the melt number and the name of the manufacturer stamped or rolled upon it. Steel for pins and rollers shall be stamped on the end. Rivet and lattice steel and other small parts may be bundled with the above marks on an attached metal tag.

18. REJECTIONS. Material which, subsequent to the above tests at the mills and its acceptance there, develops weak spots, brittleness, cracks, or other imperfections, or is found to have injurious defects, will be rejected at the shop and shall be replaced by the manufacturer at his own cost.

19. PERMISSIBLE VARIATIONS. A variation in cross section or weight of each piece of steel of more than $2\frac{1}{2}$ per cent from that specified will be sufficient cause for rejection, except in case of sheared plates, which will be covered by the following permissible variations, which are to apply to single plates.

When Ordered to Weight.

Plates $12\frac{1}{2}$ *lbs. per sq. ft. or heavier:*

(*c*) Up to 100 ins. wide, $2\frac{1}{2}$ per cent above or below the prescribed weight.

(*d*) 100 ins. wide and over, 5 per cent above or below.

Plates under $12\frac{1}{2}$ *lbs. per sq. ft.:*

(*e*) Up to 75 ins. wide, $2\frac{1}{2}$ per cent above or below.

(*f*) 75 ins. and up to 100 ins. wide, 5 per cent above or 3 per cent below.

(*g*) 100 ins. wide and over, 10 per cent above or 3 per cent below.

When Ordered to Gauge.

Plates will be accepted if they measure not more than 0.01 in. below the ordered thickness.

An excess over the normal weight, corresponding to the dimensions on the order, will be allowed for each plate, if not more than shown in the following tables, 1 cu. in. of rolled steel being assumed to weigh 0.2833 lb.

Plates $\frac{1}{4}$ *in. and over in thickness:*

Thickness Ordered.	Nominal Weights.	Width of Plate.			
		Up to 75 Inches.	75 Inches and up to 100 Inches.	100 Inches and up to 115 Inches.	Over 115 Inches.
Inches.	Lbs. per Sq. Ft.	Per cent.	Per cent.	Per cent.	Per cent.
$\frac{1}{4}$	10.20	10	14	18	....
$\frac{5}{16}$	12.75	8	12	16	....
$\frac{3}{8}$	15.30	7	10	13	17
$\frac{7}{16}$	17.85	6	8	10	13
$\frac{1}{2}$	20.40	5	7	9	12
$\frac{9}{16}$	22.95	$4\frac{1}{2}$	$6\frac{1}{2}$	$8\frac{1}{2}$	11
$\frac{5}{8}$	25.50	4	6	8	10
Over $\frac{5}{8}$	....	$3\frac{1}{2}$	5	$6\frac{1}{2}$	9

Plates under ¼ in. thickness:

Thickness Ordered.	Nominal Weights.	Width of Plate.		
		Up to 50 Inches.	50 Inches and up to 70 Inches.	Over 70 Inches.
Inches.	Lbs. per Sq. Ft.	Per cent.	Per cent.	Per cent.
⅛ up to 5/32	5.10 to 6.37	10	15	20
5/32 up to 3/16	6.37 to 7.65	8½	12½	17
3/16 up to ¼	7.65 to 10.20	7	10	15

20. INSPECTING AND TESTING. The purchaser shall be furnished complete copies of mill orders, and no material shall be rolled, nor work done, before the purchaser has been notified where the orders have been placed, so that he may arrange for the inspection.

21. The manufacturer shall furnish all facilities for inspecting and testing the weight and quality of all material at the mill where it is manufactured. He shall furnish a suitable testing machine for testing the specimens, as well as prepare the pieces for the machine free of cost.

22. When an inspector is furnished by the purchaser to inspect material at the mills, he shall have full access at all times to all parts of mills where material to be inspected by him is being manufactured.

APPENDIX VI.

STANDARD SPECIFICATIONS OF THE AMERICAN SOCIETY FOR TESTING MATERIALS FOR STRUCTURAL STEEL FOR BUILDINGS.*

(Adopted by the Society, August 16, 1909.)

1. Manufacture. Structural steel may be made by either the open-hearth or Bessemer process.

Rivet steel and plate or angle material over ¾ in. thick, which is to be punched, shall be made by the open-hearth process.

2. Chemical and Physical Properties. The chemical and physical properties shall conform to the following limits:

Properties Considered.	Structural Steel.	Rivet Steel, Open-hearth.
Phosphorus, max., Bessemer	0.10 per cent	....
Phosphorus, max., open-hearth	0.06 per cent	0.06 per cent
Ultimate tensile strength, lbs. per sq. in.	55,000–65,000	48,000–58,000
Yield point	½ ult. tens. str.	½ ult. tens. str.
Elongation, min. per cent in 8 ins., (Fig. 67)	$\frac{1,400,000^*}{\text{Ult. tens. str.}}$	$\frac{1,400,000}{\text{Ult. tens. str.}}$
Character of fracture	Silky	Silky
Cold bend without fracture	180° to diam. of 1 thickness	180° flat

* See paragraph 7.

For the purposes of these specifications, the yield point shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine.

3. Chemical Determinations. In order to determine if the material conforms to the chemical limitations pre-

* Authorized reprint from Proceedings of the American Society for Testing Materials, Vol. 9, pages 47–50.

scribed in paragraph 2 herein, analysis shall be made by the manufacturer from a test ingot taken at the time of pouring of each melt or blow of steel, and a correct copy of such analysis shall be furnished to the engineer or his inspector.

4. Form of Specimens. Specimens for tensile and bending tests shall be made by cutting coupons from the finished product, which shall have both faces rolled and both edges milled to the form shown by Fig. 67 (page 238); or with both edges parallel; or they may be turned to a diameter of ¾ in. for a length of at least 9 ins., with enlarged ends.

(*a*) For material more than ¾ in. thick the bending test specimen may be 1 in. by ½ in. in section.

(*b*) Rivet rounds and small rolled bars shall be tested as rolled.

5. Annealed Specimens. Material which is to be used without annealing or further treatment shall be tested in the condition in which it comes from the rolls. When material is to be annealed or otherwise treated before use, the specimens for tensile tests, representing such material, shall be cut from properly annealed or similarly treated short lengths of the full section of the bar.

6. Number of Tests. At least one tensile and one bending test shall be made from each melt or blow of steel as rolled. In case steel differing ⅜ in. and more in thickness is rolled from one melt or blow, a test shall be made from the thickest and thinnest material rolled. Should either of these test specimens develop flaws, or should the tensile test specimen break outside of the middle third of its gauged length, it may be discarded and another test specimen substituted therefor. In case a tensile test specimen does not meet the specification, additional tests may be made.

(*c*) The bending test may be made by pressure or by blows.

7. Modifications in Elongation for Thin and Thick Material. For material less than $\frac{5}{16}$ in. or more than $\frac{3}{4}$ in. in thickness, the following modifications shall be made in the requirements for elongation:

(*d*) For each increase of $\frac{1}{8}$ in. in thickness above $\frac{3}{4}$ in., a deduction of 1 shall be made from the specified percentage of elongation.

(*e*) For each decrease of $\frac{1}{16}$ in. in thickness below $\frac{5}{16}$ in. a deduction of $2\frac{1}{2}$ shall be made from the specified percentage of elongation.

(*f*) For pins, the required percentage of elongation shall be 5 less than that specified in paragraph 2, as determined on a test specimen, the center of which shall be 1 in. from the surface.

8. Finish. Finished material must be free from injurious seams, flaws, or cracks, and have a workmanlike finish.

9. Branding. Test specimens and every finished piece of steel shall be stamped with melt or blow number, except that small pieces may be shipped in bundles securely wired together, with the melt or blow number on a metal tag attached.

10. Variation in Weight. A variation in cross section or weight of each piece of steel of more than $2\frac{1}{2}$ per cent from that specified will be sufficient cause for rejection, except in case of sheared plates, which will be covered by the following permissible variations, which are to apply to single plates.

When Ordered to Weight.

Plates $12\frac{1}{2}$ *lbs. per sq. ft. or heavier:*

(*g*) Up to 100 ins. wide, $2\frac{1}{2}$ per cent above or below the prescribed weight.

(*h*) 100 ins. wide and over, 5 per cent above or below.

Plates under 12½ *lbs. per sq. ft.:*

(*i*) Up to 75 ins. wide, 2½ per cent above or below.

(*j*) 75 ins. and up to 100 ins. wide, 5 per cent above or 3 per cent below.

(*k*) 100 ins. wide and over, 10 per cent above or 3 per cent below.

When Ordered to Gauge.

Plates will be accepted if they measure not more than 0.01 in. below the ordered thickness.

Plates ¼ *in. and over in thickness:*

Thickness Ordered.	Nominal Weights.	Width of Plate.			
		Up to 75 Inches.	75 Inches and up to 100 Inches.	100 Inches and up to 115 Inches.	Over 115 Inches.
Inches.	Lbs. per Sq. Ft.	Per cent.	Per cent.	Per cent.	Per cent.
¼	10.20	10	14	18	....
5/16	12.75	8	12	16	....
⅜	15.30	7	10	13	17
7/16	17.85	6	8	10	13
½	20.40	5	7	9	12
9/16	22.95	4½	6½	8½	11
⅝	25.50	4	6	8	10
Over ⅝	....	3½	5	6½	9

Plates under ¼ *in. in thickness:*

Thickness Ordered.	Nominal Weights.	Width of Plate.		
		Up to 50 Inches.	50 Inches and up to 70 Inches.	Over 70 Inches.
Inches.	Lbs. per Sq. Ft.	Per cent.	Per cent.	Per cent.
⅛ up to 5/32	5.10 to 6.37	10	15	20
5/32 up to 3/16	6.37 to 7.65	8½	12½	17
3/16 up to ¼	7.65 to 10.20	7	10	15

An excess over the nominal weight corresponding to the dimensions on the order will be allowed for each plate, if not more than that shown in the preceding tables, 1 cu. in. of steel being assumed to weigh 0.2833 lb.

11. INSPECTION. The inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications.

All tests and inspections shall be made at the place of manufacture, prior to shipment.

APPENDIX VII.

STANDARD SPECIFICATIONS OF THE AMERICAN SOCIETY FOR TESTING MATERIALS FOR OPEN-HEARTH BOILER PLATE AND RIVET STEEL.*

(ADOPTED BY THE SOCIETY, AUGUST 16, 1909.)

1. MANUFACTURE. Steel shall be made by the open-hearth process.

2. CHEMICAL AND PHYSICAL PROPERTIES. There shall be three classes of open-hearth boiler plate steel; namely, flange steel, fire-box steel, and extra soft steel, which shall conform to the following limits in chemical and physical properties:

Properties Considered.	Flange Steel.	Fire-box Steel.	Extra Soft Steel.
Phosphorus shall not exceed: Acid	0.06 per cent	0.06 per cent	0.04 per cent
Phosphorus shall not exceed: Basic	0.04 per cent	0.03 per cent	
Sulphur shall not exceed	0.05 per cent	0.04 per cent	0.04 per cent
Manganese	0.30 to 0.60%	0.30 to 0.50%	0.30 to 0.50%
Ult. tensile strength, pounds per sq. in.	55,000–65,000	52,000–62,000	45,000–55,000
Yield point, in pounds per sq. in., shall not be less than	½ ult. tens. str.	½ ult. tens. str.	½ ult. tens. str.
Elongation, per cent in 8 ins., shall not be less than	$\frac{1,500,000}{\text{Ult. tens. str.}}$	$\frac{1,500,000}{\text{Ult. tens. str.}}$	$\frac{1,500,000^{*}}{\text{Ult. tens. str.}}$
Cold bend, Quench bend	180° flat	180° flat	180° flat

* But need not exceed 30 per cent.

(*a*) *Yield Point.* For the purposes of these specifications, the yield point shall be determined by the careful obser-

* Authorized reprint from Proceedings of the American Society for Testing Materials, Vol. 9, pages 51–55.

vation of the drop of the beam or halt in the gauge of the testing machine.

3. Boiler Rivet Steel. Steel for boiler rivets shall be of the extra soft class, as specified in paragraph 2.

4. Modifications in Elongation for Thin and Thick Material. For material less than $\frac{5}{16}$ in. or more than $\frac{3}{4}$ in. in thickness, the following modifications shall be made in the requirements for elongation:

(*b*) For each increase of $\frac{1}{8}$ in. in thickness above $\frac{3}{4}$ in., a deduction of 1 shall be made from the specified percentage of elongation.

(*c*) For each decrease of $\frac{1}{16}$ in. in thickness below $\frac{5}{16}$ in., a deduction of $2\frac{1}{2}$ shall be made from the specified percentage of elongation.

5. Chemical Determinations. In order to determine if the material conforms to the chemical limitations prescribed in paragraph 2 herein, analysis shall be made by the manufacturer from a test ingot taken at the time of the pouring of each melt of steel, and a correct copy of such analysis shall be furnished to the engineer or his inspector. A check analysis may be made by the purchaser or his representative, from a broken tensile-test specimen representing each heat of flange or extra soft steel on an order, and for each plate as rolled of fire-box steel, in which cases an excess of 25 per cent above the required limits in phosphorus and sulphur will be allowed.

6. Test Specimen for Tensile Test. The standard tensile-test specimen of 8-in. gauged length shall be used to determine the physical properties specified in paragraphs 2 and 3. The standard shape of the tensile-test specimen for sheared plates shall be as shown in Fig. 67 (page 238).

For other material the tensile-test specimen may be the same as for sheared plates, or it may be planed or turned parallel throughout its entire length, and in all cases where

possible two opposite sides of the test specimens shall be rolled surfaces.

Rivet rounds and small rolled bars shall be tested of full size as rolled.

7. Test Specimens for Bending Tests. The bending-test specimen shall be $1\frac{1}{2}$ ins. wide, if possible, and for all material $\frac{3}{4}$ in. or less in thickness the test specimen shall have the natural rolled surface on two opposite sides; but for material more than $\frac{3}{4}$ in. thick, the bending-test specimen may be $\frac{1}{2}$ in. thick. The sheared edges of bending-test specimens shall be milled or planed. The bending test may be made by pressure or by blows. The cold bending test shall be made on material in the condition in which it is to be used, and prior to the quenched bending test, the specimen shall be heated to a light cherry red as seen in the dark, and quenched in water, the temperature of which is between 80° and 90° Fahr.

Rivet rounds shall be tested of full size as rolled.

8. Homogeneity Tests. For fire-box steel a sample taken from a broken tensile-test specimen shall not show any single seam or cavity more than $\frac{1}{4}$ in. long in either of the three fractures obtained on the test for homogeneity as described below.

(*d*) The homogeneity test is made as follows: A portion of the broken tensile-test specimen is either nicked with a chisel or grooved on a machine, transversely about $\frac{1}{16}$ in. deep in three places about 2 ins. apart. The first groove should be made on one side, 2 ins. from the square end of the specimen; the second 2 ins. from it on the opposite side; and the third, 2 ins. from the last, and on the opposite side from it. The test specimen is then put in a vise, with the first groove about $\frac{1}{4}$ in. above the jaws, care being taken to hold it firmly. The projecting end of the test specimen is then broken off by means of a hammer, a number of light blows being used, and the bending being away from the groove. The specimen is broken at the other two grooves

in the same way. The object of this treatment is to open and render visible to the eye any seams due to failure to weld up, or to foreign interposed matter, or cavities due to gas bubbles in the ingot. After rupture, one side of the fracture is examined, a pocket lens being used if necessary, and the length of the seams and cavities is determined.

9. NUMBER OF TESTS. Three test pieces shall be furnished from each plate as it is rolled; one for tension, one for cold bending, and one for quench bending test. For rivet rods, two tensile-test specimens and two cold bending- and two quench bending-test specimens shall be furnished from each melt. In case any one of these develops flaws, or should a tensile-test specimen break outside of the middle third of its gauged length, it may be discarded and another test specimen substituted therefor.

10. PERMISSIBLE VARIATIONS. A variation in cross section or weight of each piece of steel of more than 2½ per cent from that specified will be sufficient cause for rejection except in case of sheared plates, which will be covered by the following permissible variations, which are to apply to single plates.

WHEN ORDERED TO WEIGHT.

Plates 12½ *lbs. per sq. ft. or heavier:*

(*e*) Up to 100 ins. wide, 2½ per cent above or below the prescribed weight.

(*f*) 100 ins. wide and over, 5 per cent above or below.

Plates under 12½ *lbs. per sq. ft.:*

(*g*) Up to 75 ins. wide, 2½ per cent above or below.

(*h*) 75 ins. and up to 100 ins. wide, 5 per cent above or 3 per cent below.

(*i*) 100 ins. wide and over, 10 per cent above or 3 per cent below.

When Ordered to Gauge.

Plates will be accepted if they measure not more than 0.01 in. below the ordered thickness.

An excess over the normal weight corresponding to the dimensions on the order will be allowed for each plate, if not more than that shown in the following tables, 1 cu. in. of rolled steel being assumed to weigh 0.2833 lb.

Plates ¼ in. and over in thickness:

Thickness Ordered.	Nominal Weights.	Width of Plate.			
		Up to 75 Inches.	75 Inches and up to 100 Inches.	100 Inches and up to 115 Inches.	Over 115 Inches.
Inches.	Lbs. per Sq. Ft.	Per cent.	Per cent.	Per cent.	Per cent.
¼	10.20	10	14	18	....
5/16	12.75	8	12	16	....
⅜	15.30	7	10	13	17
7/16	17.85	6	8	10	13
½	20.40	5	7	9	12
9/16	22.95	4½	6½	8½	11
⅝	25.50	4	6	8	10
Over ⅝	....	3½	5	6½	9

Plates under ¼ in. in thickness:

Thickness Ordered.	Nominal Weights.	Width of Plate.		
		Up to 50 Inches.	50 Inches and up to 70 Inches.	Over 70 Inches.
Inches.	Lbs. per Sq. Ft.	Per cent.	Per cent.	Per cent.
⅛ up to 5/32	5.10 to 6.37	10	15	20
5/32 up to 3/16	6.37 to 7.65	8½	12½	17
3/16 up to ¼	7.65 to 10.20	7	10	15

11. Branding. Each plate shall be distinctly stamped with its heat or slab number, and with the name of the

manufacturer, grade, and lowest tensile strength specified. Each test specimen shall be distinctly stamped with the heat or slab number which it represents.

Rivet steel may be shipped in securely fastened bundles with the melt number stamped on a metal tag attached.

12. FINISH. All finished material shall be free from injurious surface defects and laminations, and must have a workmanlike finish.

13. INSPECTION. The inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

APPENDIX VIII.

REQUIREMENTS FOR PAVING BRICK.

The results of rattler tests* upon paving brick have shown, for the N. B. M. A. standard test, losses varying from less than 20 per cent to more than 35 per cent for brick which have given satisfactory service.

The requirements† recommended by Committee D of the American Society for Testing Materials for compression, transverse, absorption, and freezing and thawing tests, when tested in accordance with the methods ‡ which they recommend, are as follows:

Modulus of Rupture.	Average.	Minimum.
	Pounds.	Pounds.
For samples thoroughly dry	400	325
For samples thoroughly saturated	275	225
For samples subjected to freezing and thawing process	275	225

Ultimate Compressive Strength.	Average.	Minimum.
	Lbs. per Sq. Inch.	Lbs. per Sq. Inch.
For samples thoroughly dry	3000	2500
For samples thoroughly saturated	2500	2000
For samples subjected to freezing and thawing process	2500	2000

* See Baker's "Roads and Pavements."

† Proceedings of the American Society for Testing Materials, Vol. 9, page 134.

‡ See Problems E1, E2, E3, E4.

ABSORPTION. The absorption shall not average higher than 15 per cent, and in no case shall it exceed 20 per cent.

FREEZING AND THAWING. The freezing and thawing tests shall not cause cracking or serious spalling in any of the bricks tested, nor cause serious disintegration of the material.

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